While they last, single copies of this report are available on request from USDA-ARS, Southwest Rangeland Watershed Research Center, 442 E. 7th Street, Tucson, AZ 85705.

Cover Photograph: Erosion from rangelands is often severe because of sparse vegetation and because of sediment detached in rills and gullies such as that shown in the Santa Rita Experimental Range near Tucson, Arizona.

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Proceedings of the Workshop on ESTIMATING EROSION and SEDIMENT YIELD on RANGELANDS

Tucson, Arizona
March 7-9, 1981

E. R. Burroughs, Jr.	J. M. Laflen	K. G. Renard
J. C. Chugg	L. J. Lane	M. B. Rollins
G. E. Dissmeyer	C. J. Lovely	E. D. Shirley
D. A. Farrell	D. K. McCool	J. R. Simanton
G. R. Foster	L. D. Meyer	J. J. Stone
K. A. Gebhardt	W. C. Moldenhauer	E. S. Sundberg
G. E. Hart	E. L. Neff	J. R. Wight
C. W. Johnson	R. J. Page	J. R. Williams

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PREFACE

Estimates of erosion and sediment yield in the rangeland areas of the western United States are difficult to make because of limited data. Furthermore, much of the erosion technology used in the western rangelands is based upon research completed in the cultivated agricultural areas of midwestern and eastern areas of the country where the vegetation and soils are quite different from that of western rangelands. Increased emphasis on water quality considerations, an emphasis to improve the use of and production of rangelands, and the expanding populations and their demands for multiple uses on the public lands in the western United States have accelerated the need for erosion information in such areas.

Much of the recent literature on erosion estimates in rangelands results from rainfall simulator equipment. A Rainfall Simulator Workshop held in Tucson, Arizona in March 1979 resulted in the publication of a proceedings (USDA, Science and Education Administration, Agricultural Reviews and Manuals, ARM-W-10/ July 1979) which described many simulators and nozzle designs for reproducing the kinetic energy of natural storms. However, this workshop did not discuss such things as recommended plot sizes and selection of appropriate parameter values for the Universal Soil Loss Equation.

As a result of discussions between G. R. Foster and K. G. Renard, a proposal for the convening of another workshop was prepared in the summer of 1980. An organizing committee of K. G. Renard, chairman, W. C. Moldenhauer, Lafayette, IN, and L. D. Meyer, Oxford, MS, was appointed to arrange the March 1981 Rangeland Erosion workshop.

The committee thanks D. A. Farrell, of the ARS National Program Staff, Beltsville, MD for his encouragement, suggestions, and support in organizing and conducting the workshop. However, credit for the success of the workshop belongs to the participants who gave oral presentations, participated in the discussions during the workshop, and finally prepared written comments. The committee sincerely appreciates the interest, enthusiasm, and discussions by those who attended.

Kenneth G. Renard, Chairman
Tucson, Arizona

AGENDA

Estimating Erosion and Sediment Yield on Rangelands

Tucson, Arizona

March 3, 1981 - Chairman: K. G. Renard		SPEAKER
0830-0900	INTRODUCTIONS - WORKSHOP OBJECTIVES	K. G. Renard
0900-0945	Development of USLE, Background and History (Development from 1930's to Zingg, Musgrave)	L. D. Meyer
0945-1030	Significance, Meaning, and Derivation of Each Factor in USLE with Emphasis on Rangeland Applications	G. R. Foster
1030-1045	Break	
1045-1145	Case Histories of Experiences with USLE - Step by Step Application to Some Actual Problems	D. Fulton, SCS C. Lovely, BLM D. Phillippi, SCS
1300-1700	Field Tour - Santa Rita Experimental Range: Application of USLE to Problem Area. View Operation of a Rotating Boom Rainulator	

March 4, 1981 - Chairman: D. A. Farrell		Panel Discussions Headed by
0800-1145	Special Problems of USLE	
	A. Variability of R	L. J. Lane
	B. Soil Erodibility (K)	J. M. Laflen
	C. Slope Length and Steepness (LS)	D. K. McCool
	D. C and P Factors (Including Erosion Pavements)	G. R. Foster
1145-1300	Lunch	

Afternoon Chairman: L. D. Meyer

1300-1345	Application of USLE with Snowmelt	D. K. McCool and C. W. Johnson
1345-1615	Use of Rainfall Simulators to Determine Erosion Parameters (20 minutes each)	G. F. Gifford G. E. Hart J. M. Laflen

March 4, 1981 (Continued)

1500-1515	Break	
1615-1700	Simulating Sediment Yield with CREAMS - Kinematic Cascade Runoff Model with Rill/ Interrill Erosion and Sediment Transport	L. J. Lane and G. R. Foster

March 5, 1981 - Morning Chairman: Collis Lovely

0800-0900	Sediment Yield from Small Watersheds (PSIAC, Dendy/Bolton, Flaxman, etc., Methods)	K. G. Renard & C. W. Johnson
0900-0945	Sediment Yield Using MUSLE	J. R. Williams
0945-1030	USFS Experience with USLE	G. Dissmeyer
1030-1100	Break	
1100-1200	Designing Logging Roads for Erosion Control (Experience with CREAMS)	E. Sundberg

Afternoon Chairman: G. R. Foster

1300-1400	Panel Discussion - T-Values on Rangelands	G. R. Foster (Chairman) C. Lovely J. Holeman A. G. Darrach J. R. Wight
1400-1445	Soil Erosion/Soil Productivity Planning	J. R. Williams
1500-1630	Recommendations for Research 1. What has been done? 2. What needs to be done? 3. Utility of large and small simulators. 4. Utility of natural rainfall plots. Workshop Recommendations for Including Data Needs for R, K, P, C, LS, etc.	D. A. Farrell (Chairman) E. L. Neff (Recorder)

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SOIL EROSION RESEARCH LEADING TO DEVELOPMENT OF THE UNIVERSAL SOIL LOSS EQUATION

L. D. Meyer, SEA-AR agricultural engineer[1/]

INTRODUCTION

Suppose this was 50 years ago and you had to estimate the soil erosion from an area of land or compare the erosion on it for several different land uses. Where would you start? You would have no relationships for computing the erosion and very little data upon which to base your estimations. How would you proceed?

This dilemma faced soil conservationists less than a half century ago, yet today we can readily make accurate estimates for many conditions. Erosion prediction has come a long way in less than 50 years, yet there are still many opportunities to make improvements. To understand where we are, a review of the history that led to development of the Universal Soil Loss Equation (USLE) in the form that it is used today is appropriate. Several publications (Browning, 1977; Harper, 1958; Nelson, 1958; Nichols and Smith, 1957; Smith, 1941; Smith and Wischmeier, 1960; 1962; Stewart, et al., 1976; Williams, 1958; Wischmeier and Smith, 1965; 1978; Wischmeier et al., 1958; Zingg, 1940) were particularly helpful in assembling information on the history of soil erosion research in the United States.

EARLY EROSION RESEARCH

A German scientist, Ewald Wollny (1888) has been called the "pioneer of soil and water conservation research" (Baver, 1938). In the last quarter of the 19th century, he made extensive investigations of the physical properties of soil that affect runoff and erosion. He studied the effect of various factors, including steepness of slope, plant cover, soil type, and direction of exposure, on runoff and erosion from small plots under natural rainfall. He also studied factors affecting percolation, transpiration, and evaporation from soils, and he investigated effects of compaction on the physical properties of soil. However, Wollny's discoveries were apparently overlooked by American researchers until the mid-1930's (Nelson, 1958).

The earliest quantitative erosion research measurements made in the United States were begun in 1912 on overgrazed rangelands in central Utah by A. W. Sampson assisted by L. H. Weyl, E. V. Storm, and C. L. Forsling

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1/ USDA Sedimentation Laboratory, Science and Education Administration, Agricultural Research, U.S. Department of Agriculture, Oxford, MS 38655.

(Sampson and Weyl, 1919; Stewart and Forsling, 1931). This work was conducted on two 10-acre plots in the Manti National Park, where a number of factors influencing erosion were studied. Other early work on rangelands (Chapline, 1929) showed how overgrazing allowed erosion to reduce the soil's water-retaining ability and fertility.

Erosion plot research as we know it today was started in 1917 at the Missouri Agricultural Experiment Station by Dean M. F. Miller and his associates (Duley and Miller, 1923; Miller, 1929; Miller and Krusekopf, 1932). Dean Miller's early plots were 90.75 feet long by 6.0 feet wide (1/80 acre). They are now a national historical monument on the University of Missouri-Columbia campus. Other researchers followed Miller's lead, using many of the techniques developed by him and his early assistants.

During the 1920's, H. H. Bennett, a soil surveyor in the USDA Bureau of Soils, became increasingly concerned that soil erosion was a national menace to our soil resources (Bennett and Chapline, 1928)*. Bennett undoubtedly had more influence on soil conservation efforts in the United States than any other person and very aptly deserves recognition as the father of soil conservation in our country. His evangelistic zeal for the need of erosion control and enthusiasm to start needed research led to Congressional appropriations for soil erosion investigations in 1929. With L. A. Jones, Bennett supervised the establishment of 10 experiment stations at Guthrie, Oklahoma; Temple, Texas; Hays, Kansas; Tyler, Texas; Bethany, Missouri; Statesville, North Carolina; Pullman, Washington; Clarinda, Iowa; LaCrosse, Wisconsin; and Zanesville, Ohio. The techniques that Miller and his associates had developed for evaluating runoff and erosion were followed at these research stations. Most plots were 72.6 feet long by 6.0 feet wide (0.01 acre). The data and findings were published during the 1930's and 40's in progress reports from these stations. Other field experiments and more field locations were added in the 1940's and 50's to investigate a wider range of conditions (Smith and Wischmeier, 1962).

Bennett served as chief of the Soil Conservation Service during much of the 1930's and apparently was one of the most popular speakers and prolific writers of that time. He was widely respected as indicated by the Albuquerque Journal on August 28, 1937:

> "Bennett pays no attention to the politics of farm relief. His religion is the saving of soils--that means he knows no south or north, no radical or reactionary. Farmers have confidence in him--he delivers the goods."

During the 1930's and early 40's, research on the more fundamental aspects of soil erosion processes was begun by H. E. Middleton (1930), J. F. Lutz (1934), R. E. Horton (1933), G. W. Musgrave (1935), L. D. Baver (1937), J. H. Neal (1938), J. O. Laws (1940), W. D. Ellison (1947), and others. These pre-World War II years were "relatively golden years for soil conservation research," because, as discussed by Nelson (1958), the problem

*(Part 2 of this publication, authored by W. R. Chapline, is entitled "Soil Erosion on Western Grazing Land")

had been recognized, research procedures had been established, a spirit of pioneering and enthusiasm was found among the researchers, fundamental research was encouraged, the need for results was recognized nationally, and adequate funds were available for staffing and facilities. Yet, research techniques were relatively crude in many respects. Runoff and erosion for each entire storm were usually caught in large tanks for measurement, often with no indication of time-rate information. A common experimental design was followed, but treatments were seldom randomized or replicated. Conditions studied were very limited and plot conditions were often quite different than natural farming conditions. Nevertheless, a large quantity of data was obtained, although the usefulness of any part of it beyond the local situation was quite limited. In Bennett's (1939) classic book "Soil Conservation", considerable data are presented, but there are no mathematical relationships concerning the effects of different factors on erosion nor is there any discussion of erosion prediction techniques.

EARLY EROSION EQUATIONS

The basis for mathematical relationships to describe soil erosion probably began with efforts such as those by H. L. Cook (1936) to identify the major variables involved. He listed three major factors: (1) the susceptibility of soil to erosion (soil erodibility) including the need for tests to evaluate an erodibility index, (2) the potential erosivity of rainfall and runoff including the influence of degree of slope and slope length, and (3) the protectivity afforded by vegetal cover. He described in much detail the subfactors affecting each of these major factors.

The use of equations to calculate field soil loss began when A. W. Zingg (1940) published the results of his comprehensive study on the effect of degree of slope (S) and slope length (L) on soil loss. Using data from other researchers and his own experiments, he recommended the relationship, $X = CS^{1.4}L^{1.6}$, where C is a constant of variation and X is the total soil loss; or $A = CS^{1.4}L^{0.6}$, where A is the average soil loss per unit of area. (Note: In early erosion equations, L and S were used as slope length and slope steepness; later, they were used as factors that were different than, but functions of, slope length and slope steepness. In general, the terminology and symbols in this paper are those used by the researchers, so they may differ from current usage.)

The following year, D. D. Smith (1941) added crop (C) and supporting practice (P) factors to the equation as: $A = C\ S^{7/5}\ L^{3/5}\ P$, and he used this to develop a graphical method for selecting the necessary conservation practices on Shelby and associated soils in the Midwest. The C-factor included the effects of weather and soil as well as cropping system. Smith also introduced the concept of a specific annual soil loss limit for Midwestern soils.

Several important publications that appeared during the late 1940's were probably delayed by World War II. Browning and his associates (1947) evaluated the Smith (1941) equation for Iowa soils and introduced more extensive tables of relative factor values for different soils, rotations,

and slope lengths. This approach emphasized the evaluation of slope-length limits for different cropping systems on specific soils and slope steepnesses with and without contouring, terracing, or strip cropping.

The Milwaukee, Wisconsin regional office of the Soil Conservation Service recognized the value of a soil loss estimating equation for farm planning and teamed with the research workers in that region to develop a system for regional application. The result was the slope-practice method of estimating soil loss for use throughout the Cornbelt described by Smith (1958). The "Slope-Practice Equation" was so successful that a review was requested by J. C. Dykes, SCS Chief of Operations, in 1946. This was followed by a workshop in Cincinnati, Ohio under the leadership of G. W. Musgrave (1947) to broaden the applicability of the Cornbelt equation. This group reviewed soil loss data from throughout the United States, reappraised the factors previously used, and added a rainfall factor. The so-called Musgrave Equation resulted, and it included factors for rainfall, flow characteristics of surface runoff as affected by slope steepness and slope length, soil characteristics, and vegetal cover effects. Erosion was evaluated in inches lost per year. The 1.75 power of the 2-year, 30-minute rainfall was adopted as the rainfall factor, and the slope length and steepness exponents were lowered from 0.6 and 1.4 of Zingg (1940) to 0.35 and 1.35, respectively. Annual cover factors were estimated relative to a value of 100 for either continuous fallow or continuous rowcrop. A soil factor was derived by adjusting measured annual soil losses at the experimental locations for differences in rainfall, slope, and cover. Quantitative values for the factors in this equation were quite limited, particularly for the different cropping covers. Apparently, most details on the Musgrave equation, its use, and appropriate factor values were in agency handbooks and mimeographed tables that were not published.

Subsequent research did not confirm the adequacy of the 2-year, 30-minute rainfall as an index of local differences in rainfall erosivity. The reduced slope-length factor was compatible with some early sets of data but was too low for others. Numerous plot studies showed that continuous fallow and continuous row crop are not interchangeable and that the cover effect of continuous row crops is highly variable. However, the Musgrave Equation was widely used until recent years, primarily because its highly generalized factor values were more easily assigned than were factors based on more specific conditions. Its widest use has been for estimating gross erosion from large heterogeneous watersheds and for flood abatement programs.

Smith and Whitt (1947) presented a method for estimating soil losses from fields of claypan soils. They suggested the equation, $A \propto a + bS^{4/3}$, where a and b were constants, to describe the influence of percentage slope (S), and $A \propto L^{0.6}$ to describe the effect of slope length (L) for these soils. Soil loss ratios at different slopes were given for contour farming, strip cropping, and terracing, and recommended slope length limits were presented for contour farming. Relative erosion rates for a wide range of crop rotations were also given.

The following year, Smith and Whitt (1948) presented a "rational" erosion estimating equation:

$$A = C \times S \times L \times K \times P$$

for the principal soils of Missouri. The C-factor was the average annual soil loss from claypan soils for a specific rotation on a 3% slope, 90 feet long, and farmed up and down slope. The other factors for slope (S), length (L), soil group (K), and supporting practice (P) were dimensionless multipliers to adjust the value of C to other conditions. P-factor values were discussed in much detail. The need for adding a rainfall factor to satisfactorily apply this equation over several states was acknowledged. The work reported in these two Smith and Whitt publications was actually accomplished prior to the 1946 workshop that resulted in the Musgrave Equation.

Musgrave (1949) discussed the importance of designing agronomic practices to meet specific erosion hazards. He showed how the erosive hazard of rainfall changes through the year at different locations in the United States, and he stressed the need to use cropping practices that provide soil cover during periods of serious erosion hazards.

Lloyd and Eley (1952) prepared graphs to solve the Musgrave (1947) equation for use "on the spot for a specific set of conditions." They tabulated values for major conditions found in the northeastern states. They stressed the need for practical methods of applying research findings to field conditions to help farmers and technicians understand the true value of conservation measures.

In the early 1950's, Van Doren and Bartelli (1956) proposed an erosion equation:

$A = f(T,S,L,P,K,I,E,R,M)$, where

A = annual estimated soil loss
T = measured soil loss
S = steepness of slope
L = length of slope
P = practice effectiveness
K = soil erodibility
I = intensity and frequency of 30-minute rainfall
E = previous erosion
R = rotation effectiveness
M = management

The key value for T was 3.5 tons per acre from Flanagan silt loam on 2% slope of 180-ft. length cropped continuously to corn. Estimates for other conditions were made using $S^{1.5}$, $L^{0.38}$ (L < 200 ft.) and $L^{0.60}$ (L > 200 ft.). Other factor values were given in tables and graphs for application on soils and cropping conditions throughout Illinois.

To pursue development of an erosion-prediction equation compatible with data from all over the United States, the National Runoff and Soil Loss Data Center was established in 1954 at Purdue University under the direction of W. H. Wischmeier. This pioneering effort was the result of recommendations by a group of leaders in soil and water conservation work representing the Agricultural Research Service, Soil Conservation Service, several state agricultural experiment stations, the U.S. Weather Bureau, and the U. S. Bureau of Public Roads who met at Ames, Iowa in June, 1953. The Data Center was given the responsibility of locating, assembling, and consolidating runoff and erosion data from studies throughout the United States for summarization and further analyses in an orderly fashion. The early research was conducted by Wischmeier and R. E. Uhland under supervision by D. D. Smith and with cooperation from dozens of research locations throughout the United States. This was a time when digital computers and punched cards to store and organize data were just emerging (Wischmeier, 1955). By 1956, more than 7000 plot-years and 500 watershed-years of basic precipitation, soil loss, and related data had been assembled at the Data Center (see Table 1). This voluminous data came from dozens of widely scattered research locations in many different forms and conditions. After standardizing the forms and units, the data were transferred to punched cards with a card for each runoff event, so that they could be mechanically rearranged and combined in overall statistical designs for analyses by statistical techniques. Between 1956 and 1970, several thousand additional plot-years and watershed-years of data from continuing studies and about 20 additional locations were added to this data bank as they became available. These results from studies under natural rainfall were augmented by data from erosion-plot research using simulated rainfall.

In 1955, the SCS state conservationists of the nine Midwestern states requested the latest available information on the slope-practice approach. Toward this end, joint conferences of personnel from the Soil and Water Conservation Research Branch-Agricultural Research Service, the Soil Conservation Service, and cooperating state agencies were held at Purdue University in February and July, 1956. This group concentrated their efforts on reconciling differences among the existing soil-loss equations and extending this technique to regions where no measurements of erosion by rainstorms had been made. Persons who participated in these conferences included many who now are revered for their great contributions to erosion prediction and soil conservation--L. J. Bartelli, L. L. Harrold, O. E. Hays, A. A. Klingebiel, G. W. Musgrave, D. D. Smith, C. A. VanDoren, D. M. Whitt, W. H. Wischmeier, and A. W. Zingg--but at that time they were more like the group assembled for this workshop--interested persons hoping to advance the science of erosion research and erosion control. The deliberations and conclusions of that group were summarized in mimeographed workshop reports, with some details published by Smith and Wischmeier (1957) and Wischmeier et al., (1958). The basic equation considered at these workshops (with some workshop decisions indicated in parentheses) was:

$A = C \times M \times S \times L \times P \times K \times E$, where

A = estimated soil loss

TABLE 1.--Precipitation, runoff, soil loss, and related data assembled through February, 1956 at the National Runoff and Soil Loss Data Center*

Location	No. Plots	Plot Length (ft.)	Plot Slope (%)	Plot Yrs.	No. Wsds.	Wsd. Yrs.
GA, Tifton	9		3	36		
Watkinsville	14	35	7,11	146		
	26	70	7,11	311		
	11	105	3,7,11	89		
IL, Dixon Springs	16	35,70,140,210	5,10	96		
	22	70	8	154		
Joliet	13	100	4	39		
Urbana	4	180	2	52		
IN, Lafayette					20	258
IA, Castana	10	73	14	50		
Clarinda	3	36,73,145	9	33	5	40
	46	73	8-10	375		
	4	158,315,650	8	28		
KN, Hays	3	36,73,145	5	51	2	20
	8	73	5	119		
	16	109	4	104		
	4	200	7	24		
LA, Baton Rouge	12	100	4.4	108		
MI, East Lansing					3	39
MO, Bethany	2	36,73	8	24	6	60
	9	73	8	108		
	10	80	8.5	110		
	10	125	8	69		
	6	270	6.6	42		
	5	90,180,270	10	45		
NJ, Beemerville	6	70	16.5	18		
Marlboro	40	70,140,210	3.5	384	9	42
	2	35	4	10		
New Brunswick	16	36	3.5	80		
NY, Ithaca	3	36,73,145	18	57	5	30
	13	73	20	235		
Geneva	6	73	8	108		
	2	73	5	36		
Marcellus	31	36,73,145	16	314		

TABLE 1--Continued

Location	No. Plots	Plot Length (ft.)	Plot Slope (%)	Plot Yrs.	No. Wsds.	Wsd. Yrs.
NC, Raleigh	60	136	3-5	264		
	6	121	3-5	30		
	6	182	3-5	30		
OH, Zanesville	3	36,73,145	12	21		
	8	73	12	84		
	1	73	8	7		
OK, Guthrie	3	36,73,145	8	75		
	6	73	8	150		
	6	340	4	54		
SC, Clemson	16	18-22	7-8.5	60		
	10	62-66	8	94		
	3	66	17	5		
Spartanburg	3	73	6	12		
TX, Temple	3	36,73,145	4	64		
	9	72	4	89		
	6	135	2	50		
	5	168	3.5	56		
	12	432	2.4	192		
Tyler	3	36,73,145	9	45		
	9	73	9	135		
	2	73	12.5	28		
	16	73	6.5-8	96		
VA, Blacksburg	15	58	5,10,15 20,25	255		
WA, Pullman					7	73
WI, LaCrosse	3	36,73,145	16	21		
	24	36,73	3,8,13,18	276		
	42	73	16	531		
	10	73	18	108		
	3	73	30	21		
	24	120	20	144		
Hundt Farm	40	200-300	11	480		
Madison	29	200	8	162		
Owen	11	300	3	88	4	32

*Additional data were received later from many of these locations and from Batesville, AR; Beaconsfield, Seymour, and Independence, IA; Presque Isle, ME; Benton Harbor, MI; Morris, MN; Holly Springs and State College, MS; McCredie, MO; Hastings, NE; Statesville, N.C.; Coshocton, OH; Cherokee, OK; State College, PA; Madison, S.D.; Knoxville and Greenville, TN; and Mayaguez, PR.

C = crop rotation factor (C = 100 for continuous corn)
M = management factor (values from 0.5 to 0.8 for different residues and methods of tillage)
S = degree or percent of slope factor ($S \propto \text{slope}^{1.4}$, with continued study of a proposed quadratic relationship)
L = length of slope factor ($L \propto \text{length}^{0.5 \pm 0.1}$)
P = conservation practice factor (specific values for slopes from 1.1 to 24%)
K = soil erodibility factor (each soil given a value of 0.75, 1.0, 1.25, 1.5, or 1.75)
E = previous erosion factor (not evaluated, but considered when establishing the permissible soil loss limit for each soil)

The maximum permissible loss for any soil was established as 5 tons per acre per year, with lower limits for many soils. The workshop concluded that insufficient data were available at that time to add a rainfall factor.

Subsequent efforts by Wischmeier, Smith and others led to combination of the crop rotation and management factors (Wischmeier, 1960) and to a rainfall factor for the states east of the Rocky Mountains (Wischmeier and Smith, 1958; Wischmeier, 1959). The resulting "Universal Soil Loss Equation" (Wischmeier and Smith, 1960) was introduced in its present form at a series of Regional Soil Loss Prediction Workshops in 1959-62 and by a popular publication (USDA, 1961). The complete presentation of the USLE was in Agriculture Handbook 282 (Wischmeier and Smith, 1965), which has been revised (Wischmeier and Smith, 1978).

The Universal Soil Loss Equation* (Wischmeier and Smith, 1965; 1978; Wischmeier, 1976) is:

$A = R \times K \times L \times S \times C \times P$, where

$\underline{A}$ is the predicted soil loss per unit of area as computed by multiplying values for the other six factors. As usually used, it is an estimate of the average annual interrill plus rill erosion from rainstorms for field-sized upland areas. It generally does not include erosion from gullies or streambanks, snowmelt erosion, or wind erosion, but it does include eroded sediment that may subsequently deposit before it reaches downslope streams or reservoirs.

$\underline{R}$ is the rainfall and runoff factor for a specific location, usually expressed as average annual erosion index units.

$\underline{K}$ is the soil erodibility factor for a specific soil horizon, expressed as soil loss per unit of area per unit of R for a unit plot. (A unit plot is 72.6 feet long with a uniform 9% slope maintained in continuous fallow with tillage when necessary to break surface crusts.

*The USLE was developed and is still widely used in English units. Information on conversion to metric units is given in the Appendix of Wischmeier and Smith, 1978.

These dimensions were selected because most early erosion research plots in the United States were 72.6 feet long and had slopes near 9%. Continuous fallow was selected as a base, because no cropping system is common to all agricultural areas and soil loss from any other plot condition would be influenced by residual and current crop and management effects that vary from one location to another.)

L is the dimensionless slope-length factor (not the actual slope length) expressed as the ratio of soil loss from a given slope length to that from a 72.6-ft. length under the same conditions.

S is the dimensionless slope-steepness factor (not the actual slope steepness), expressed as the ratio of soil loss from a given slope steepness to that from a 9-percent slope under the same conditions.

C is the dimensionless cover and management or cropping-management factor, expressed as a ratio of soil loss from the condition of interest to that from tilled continuous fallow.

P is the dimensionless supporting erosion-control practice factor, expressed as a ratio of the soil loss with practices such as contouring, strip cropping, or terracing to that with farming up and down the slope.

The USLE is the most comprehensive technique currently available for estimating erosion on sloping fields. It includes the six major factors that affect upland soil erosion by water: rainfall erosiveness, soil erodibility, slope length, slope steepness, cropping and management techniques, and supporting conservation practices. It is a methodical procedure developed from statistical analyses of more than 10,000 plot-years of data from runoff plots and small watersheds at about 50 locations in 24 states. It enables land-management planners to estimate average annual erosion rates for a wide range of rainfall, soil, slope, crop, and management conditions and to select alternative land-use-and-practice combinations that will limit erosion rates to acceptable levels. The factor relationships used may change from time to time, but the major factors in this equation will remain as major determinants of erosion.

The USLE overcame many of the deficiencies of its predecessors. Its form is similar to that of the Slope-Practice and Musgrave equations, but the concepts, relationships, and procedures underlying the definitions and evaluations of the erosion factors are distinctly different. Major changes included (1) more complete separation of factor effects so that results of a change in a level of one or several factors can be more accurately predicted, (2) an erosion index that provides a more accurate localized estimate of the erosive potential of rainfall and its associated runoff, (3) a quantitative soil-erodibility factor that is evaluated directly from research data without reference to any common benchmark, (4) an equation and nomograph capable of computing the erodibility factor for numerous soils from soil-survey data, (5) a method of including effects of interactions between cropping and management parameters, and (6) a method of incorporating effects of the local rainfall pattern through the year and

specific crop cultural conditions in the cover and management factor (Wischmeier, 1972).

The USLE incorporated results from erosion studies conducted at many locations during a half century of research. The findings from such research often appeared to be inconsistent and sometimes incompatible because of wide differences in the reported results. However, much of the difference could usually be explained by the specific rainfall pattern, soil properties, topographic features, and management details that occurred at different levels and at different combinations in the various studies. Erosion plot data predict specific-field soil losses only if the influence of each of the major contributing parameters can be isolated and evaluated relative to the level at which the parameter was present in the study, so that the various influences can be combined in different proportions to simulate other conditions. Effects of rainfall characteristics and soil properties cannot be isolated in a one-location study, where rainfall and soil are either constant for the plot sites or vary in unison. Various secondary variables cannot be controlled in plot studies. Some of these vary randomly with time, some differ with seasons, and others show long-term trends at a given location but fluctuate unpredictably during short time periods. By assembling all available research data at one location for overall statistical analyses, many of these limitations were overcome. Basic data were combined from various locations using analytical designs that were capable of providing information on major factor effects individually and on some of the most important interactions. Bias of results by effects of random variables was also reduced by the larger amount of data (Stewart, et al., 1976).

The term "Universal" in the USLE has been criticized by some. The explanation that follows (Wischmeier, 1972) clarifies its use:

> "The name 'universal' soil-loss equation originated as a means of distinguishing this prediction model from the highly regionalized models that preceded it. None of its factors utilizes a reference point that has direct geographic orientation. In the sense of the intended functions of the equation's six factors, the model should have universal validity. However, its application is limited to states and countries where information is available for local evaluations of the equation's individual factors. There are exceptions to the validity of the EI parameter as a measure of the combined erosive forces of rainfall and runoff. For some situations, a more accurate predictor of runoff-erosion potential needs to be substituted as the value of R. The indicated <u>nature</u> of effects of topographic, cover, and management variables is probably universal, but it has not been shown that the specific ratios for L, S and C, derived on the U. S. mainland, are necessarily accurate on vastly different soils, such as those of volcanic origin for example. Slope effect in situations where gradients appreciably exceed 20 percent is still a serious void in research information.
>
> "The relationships, graphs and tables presented for evaluation of the equation's factors cannot be simply transported

verbatim to states or countries where the type of rainfall or the soil genesis is vastly different. However, a relatively small amount of well designed local research should enable many countries to adapt the soil-loss equation and basic relationships to their situations."

The USLE was designed to meet the need for a convenient working tool for conservationists, technicians, and planners. The primary need was a relatively simple technique for predicting the most likely soil loss rates for specific situations. Therefore, refinements needed only for short-run predictions were sacrificed in the interest of conciseness and simplicity. Concepts developed by the many research efforts since 1930, and analyses of the assembled data, showed that all important parameters for soil loss prediction could be grouped under six major factors. Goals for this equation included that each of the factors (1) could be represented by a single number, (2) could be predicted from meteorological, soils, or erosion-research data on a locational basis, and (3) must be free from any geographically oriented base. Since no satisfactory runoff-prediction equation was available, the decision was made not to distinguish between predictions of runoff and its soil content in the model. Subsequent work was unsuccessful in developing a satisfactory cropland runoff prediction equation, so this decision was fortunate.

The mathematical relationship between each of the USLE factors and soil loss was determined from statistical analyses of the assembled data. The effects of slope length and steepness, crop sequence, and soil- and crop-management practices were most accurately described in the form of percentage increases or decreases in soil loss. Therefore, a multiplicative model was selected for the equation. It utilizes four dimensionless factors to modify a basic soil loss that is described by dimensional rainfall and soil factors. Thus, the USLE is a statistical equation with variables evaluated by relationships based on the best percentage of variation explained. Regression lines and correlation coefficients were key aspects of its development. Since Wischmeier was a statistician, the relationships are primarily statistical in form rather than physical.

The impact of the USLE has been tremendous since it was introduced more than 20 years ago. It has become a major soil conservation tool throughout the United States and in other countries. But as is true for any tool, its use is limited to certain purposes and it can always be improved. Also, its possible adaptation for other uses requires careful consideration of problems and pitfalls that may result. As the applicability of the USLE to rangeland conditions is assessed, the way that it was developed, the data needed to evaluate its factors, and the basis for its use need to be kept clearly in mind.

SUMMARY

To try to summarize the years leading up to the present-day USLE is difficult, but some milestones are apparent. During the teen years of this 20th century, soil erosion experimentation began on field plots. The 1920's were years of awakening to the menace of soil erosion and the need for erosion control on the agricultural lands of our nation. They were also

years when results from early experiments confirmed the fears of observant scientists and farmers that serious soil losses were occurring on poorly managed land. The 1930's were a time when field experiments were greatly expanded in number and breadth of conditions studied. Research on fundamental erosion principles also began in earnest during these years. During the 1940's, equations to describe the effects of various factors on soil loss, based on research results from earlier studies, were proposed and used successfully on a local and regional scale. Because of World War II, field experiments and fundamental research activity were seriously reduced. The 1950's were a period of expanding research effort in erosion-prediction equation development that culminated in the USLE. Much of the available data was utilized, and major gaps in knowledge were identified. These were also years when field-plot erosion research using rainfall simulators blossomed, and a time when the importance of fundamental research to complement other research was again recognized. The USLE as we use it today is truly the product of many years of inovative and dedicated effort by hundreds of persons. It was not a sudden development; instead, it evolved in a quite logical and organized way over several decades. We owe a sincere debt of gratitude to those who pioneered these important years in history.

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RELATION OF USLE FACTORS TO EROSION ON RANGELAND[1/]

G. R. Foster[2/]

ABSTRACT

Factors in the Universal Soil-Loss Equation (USLE) are measures of the effect of climate, soil, topography, and land use on erosion. The factors are referenced to a unit plot, 72.6 ft long on 9% slope, maintained in tilled, continuous fallow. The USLE is primarily used to inventory erosion under current conditions and to guide the selection of practices to control erosion to a tolerable level. It has been widely applied to cropland in the Eastern U. S. and recently has been extended to Western rangeland. Special considerations are required in this new application because rangeland conditions differ significantly from those used to derive the USLE.

INTRODUCTION

The Universal Soil-Loss Equation (USLE) (Wischmeier and Smith, 1978) is widely used to estimate sheet and rill erosion. Although the USLE was orginally developed for cropland east of the Rockies, its use has been extended to rangeland, construction sites, forest lands, and surface mines in all parts of the U. S. and in several foreign countries. The data originally used to develop the USLE were extensive, including 10,000 plot-years of data from natural runoff plots and small watersheds for a wide range of soils, slope lengths and steepnesses, crops, and management practices common to cropland in the Eastern U. S. More recently, data from plots under simulated rainfall were used to evaluate soil erodibility, conservation tillage, and erosion on construction sites. Generally, the data used to extend the USLE to the West and to rangeland were limited in comparison with the original data (Wischmeier, 1974; Wischmeier, 1975).

A generation of erosion research, data collection, equation development, and field application of erosion equations preceeded the USLE. Some of the factors and techniques used in the USLE had evolved as early as 1940 (Zingg, 1940). Consequently, the USLE was both a refinement and a major advancement of technology. Research for new applications of the USLE must consider the

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2/ Hydraulic Engineer, USDA, and Associate Professor, Agricultural Engineering Department, Purdue University, West Lafayette, Indiana.

significance, meaning, and derivation of each of its factors, particularly as they relate to conditions of climate, soil, topography, and land use that are greatly different from those which produced the original USLE data set.

USLE FACTORS

The USLE factors are measures of the effect of climate, soil, topography, and land use on erosion. The factors are:

$$A = R\ K\ L\ S\ C\ P \qquad [1]$$

where A = soil loss (mass/area time period of R), R = rainfall-runoff erosivity factor (climate), K = soil erodibility factor (soil), L = slope length factor (topography), S = slope steepness factor (topography), C = cover and management factor (land use), and P = supporting conservation practice factor (land use). Factors L, S, C, and P are dimensionless; A, R, and K have dimensions and units.*

Erosivity (R)

The product R K is a key component of the USLE. The factor R for a specific year is given by:

$$R = \sum_{j=1}^{n} (EI)_j \qquad [2]$$

where EI = the product of storm energy and maximum 30-min intensity. Not all storm EI qualify for inclusion in the sum for R (Wischmeier and Smith, 1978). For example, EI for rain storms of less than 1/2 inch are excluded because these storms generally contribute little to erosion or R. Storms separated by less than six hours are treated as a single storm. Wischmeier and Smith (1978) list all of the requirements for inclusion of a storm's EI in the summation for R.

The erosivity parameter EI was determined by regression analysis of soil loss data from 72.6 ft long natural runoff plots, maintained in continuous tilled fallow or continuous row crops (Wischmeier and Smith, 1958; Wischmeier, 1959; Wischmeier, 1972). Several rainstorm variables were analyzed to determine an erosivity factor (Table 1). Inclusion of runoff variables in the erosivity factor would have improved erosion predictions (Lombardi, 1979), but they were not used because runoff prediction equations available at the time were judged to be unsatisfactory for estimating runoff values for use in the USLE (Wischmeier, 1972).

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* Foster, G. R., D. K. McCool, K. G. Renard, and W. C. Moldenhauer. 1981. Conversion of the Universal Soil Loss Equation (USLE) to SI Metric Units. Submitted to J. of Soil and Water Conservation.

TABLE 1. Examples of percentages of total soil-loss variation accounted for by certain rain storm parameters.[1/]

Rainstorm parameter(s)	Soil type and no. of storms in analysis					
	Shelby loam		Marshall	Fayette	Cecil s. l.	
	topsoil (136)[2/]	subsoil (136)	si c l (92)	si l (115)	rep 1 (81)	rep 2 (81)
I[3/]	56	42	55	82	76	72
E	82	77	57	70	70	72
M	74	69	50	62	65	67
VxD	78	70	63	79	62	68
E + I	83	77	68	86	84	83
M + I	78	69	68	86	83	81
VxD + I	79	70	69	87	83	84
ExI	89	82	74	90	97	95
MxI	87	79	74	90	96	93
VxDxI	86	75	74	90	85	90

1/ Determined by coefficient of determination, R^2, in regression analyses with soil loss from bare fallow as the dependent variable.
2/ Number of storms.
3/ Definitions: I = maximum 30-min intensity; E = kinetic energy of the rain; M = momentum; VxD = drop velocity times diameter; the symbol "+" between parameters indicates their combination in an additive model; ExI, MxI, and VxDxI are interaction terms derived as products of the parameters.
Source : Wischmeier (1972)

Typical applications of soil loss equations at the time the USLE was developed required fairly simple equations. Since the USLE estimates long term, average annual soil loss, extra steps to estimate and use runoff values in the equation probably would not have significantly increased the accuracy of the USLE. Furthermore, EI has a major advantage because a simple, linear weighting procedure can be used to account for the interaction of the seasonal variabliity of erosivity with cover because soil loss varies linearly with EI.

Total storm energy E is given by:

$$E = \sum_{k=1}^{n} e_k \Delta V_k \quad [3]$$

where e_k = energy concentration or unit energy of the rainfall and ΔV_k = the depth of rainfall at intensity i_k. The rainfall hyetograph is divided into periods so that a constant i_k can be assumed for a period Δt_k. The depth ΔV_k is $i_k \Delta t_k$. Unit energy derived from natural rainfall data is given by (Wischmeier and Smith, 1958; Wischmeier and Smith, 1978):

$$e_k = 916 + 331 \log i_k \qquad [4]$$

where e_k has units of ft ton/(acre in of rain) and i_k has units of in/hr. Unit energy e does not vary greatly with i, and in Northern Mississippi e is nearly constant for intensities above 1 in/hr (McGregor and Mutchler, 1977; Wischmeier and Smith, 1978).

The interpretation of EI should not limit it to just a measure of the erosivity of impacting raindrops even though it is computed from their energies. Perhaps emphasis of energy relationships has detracted from the significance of EI. Since e can be assumed constant for intensities greater than 1 in/hr, total energy E for a storm is almost directly proportional to rainfall depth V for a storm. Thus EI can be written as:

$$EI = \alpha V I_{30} \qquad [5]$$

where α = a proportionality constant and I_{30} = maximum 30-min intensity. Lombardi (1979) found that $V I_{30}$ was almost as good for estimating soil loss from bare fallow plots as EI computed by the regular method.

The erosivity factor VI_{30} is a basic erosivity factor because it includes measures of the two most important properties of a rainstorm, amount and intensity. The intensity I_{30} is a measure of interrill erosion rate per unit of rainfall. This rate multiplied by total depth of rainfall gives total interrill erosion for a storm. Rill erosion rate and sediment transport capacity per unit of runoff can be assumed to be proportional to peak runoff rate which is related to I_{30}. This erosion rate and sediment transport rate multiplied by depth of runoff, which is related to depth of rainfall, would give total rill erosion and sediment transport capacity for the runoff event. Thus EI, because of its proportionality to VI_{30}, is more than a measure of the capacity of raindrops to detach soil particles; it indirectly includes the effect of runoff on rill erosion and sediment transport.

Amount of runoff depends greatly on antecedent conditions, and, since the USLE does not directly consider either antecedent conditions or specific soil and cover conditions at the time of an event, it poorly estimates soil loss from specific rain events (Wischmeier, 1976). Lombardi (1979) found that erosivity factors which combine depth of rainfall, depth of runoff, and maximum 30-min intensity were better than EI for estimating soil loss from specific storms. However, the USLE should provide a good estimate of average soil loss for many occurrences of a specific storm over the normal range of antecedent conditions.

Clearly, the infrequency of rainfall and its great spatial variablility in the West are considerations in application of the USLE (Trieste and Gifford, 1980). Perhaps accurate estimates for specific events are required when annual soil loss is very strongly dominated by one or two storms in a year. If soil loss estimates for specific events become critical in the application of the USLE, the erosivity factor R will need rexamination.

Soil Erodibility (K)

Different soils under similar conditions may erode at different rates. The K factor is a measure of this basic difference in soil erodibility. The influence of other factors, like rainfall-runoff erosivity, slope length and steepness, cover, and management, must be removed from experimental data in order to evaluate K. The approach used in the USLE development was to define a base reference, the unit plot (Wischmeier and Smith, 1978). A unit plot is 72.6 ft long on a 9% slope and is maintained in continuous fallow, periodically tilled up and down hill to break soil crust and to control weeds. Values of L, S, C, and P are defined to be unity for the unit plot. Many fallow and cropped plots in the original USLE data set were typically 72.6 ft long by 6 ft wide for an area of 0.01 acre, a unit that conveniently converted soil loss from tons/plot to tons/acre by a simple shift of the decimal point. Although 9% was an average or typical plot steepness for many of the research locations, the range in plot steepness across the various locations was from 3% to 25%. Continuous fallow was selected for the unit plot because no cropping system is common to all agricultural areas and soil loss from any other plot condition would be influenced by residual and current crop-and-management effects that vary from one location to another (Wischmeier, 1972). Such variation prevented isolation of soil erodibility. Also, soil loss from the unit plot is a reference for high erosion rates, although erosion from plots with crusted soil may be greater than that from tilled unit plots.

Soil erodibility K (mass/area erosivity unit) is defined as the rate of erosion from the unit plot of a specific soil per unit of erosivity. To determine K, soil loss from experimental plots being used to estimate K is adjusted to give the soil loss expected from a unit plot on the same soil. Adjusted soil loss is observed soil loss divided by factor values for slope length, slope steepness, cover, and management applicable to the experimental plots. The slope of the linear regression line for those adjusted soil loss values vs. EI is K (Wischmeier, 1972). The intercept of the linear regression line is ignored because it is usually close to zero, or the regression line is forced through the origin.

Values of K determined from natural runoff plots are affected by the type of rainfall and runoff and the distribution of rain on dry soil vs. rain on wet soils. Consequently, when K is derived from rainfall simulator data, measured erosion rates from both rain on dry soil and rain on wet soil are weighted to reflect the natural distribution of rainfall (Wischmeier et al., 1971).

Since K is a measure of erodibility from both raindrop impact and surface runoff, plots used to determine K must be sufficiently long for runoff to accumulate to a rate typical of most field situations. A soil's susceptibility to interrill erosion by raindrop impact (interrill erosion) may not be related to its susceptibility to erosion by surface runoff (rill erosion). Two soils may be equally susceptible to interrill erosion, but have greatly differing susceptibilities to rill erosion (Meyer et al., 1975). The relative erodibilities of two such soils depends on the slope length used to evaluate them (Meyer et al., 1976). Therefore, erosion on short plots may not accurately measure K for longer slope lengths, where rill erosion contributes significantly to soil loss.

The USLE soil erodibility nomograph (Wischmeier et al., 1971), frequently used to estimate K, was derived from rainfall simulator data from 35 ft long plots on Midwestern soils that were predominently medium textured. Obvious differences between Midwestern and Western soils raise questions about the transferability of the nomograph. The genesis of Western soils is greatly different from that of Midwestern soils, and Western soils are sometimes covered by a stone (erosion) pavement not present on many Eastern soils. Furthermore, Western rainfall patterns differ from Eastern patterns which could give different K values for the same soil located in the two climates. The effect of these differences on K has not been extensively studied.

A tilled fallow plot is used for a reference to define K. Most rangeland soils are not cultivated, and if they are tilled, like in root plowing, the disturbance is less intense than most primary and secondary tillage of agricultural soils. Furthermore, tillage on rangeland is infrequent. Therefore, tilled fallow does not represent a typical rangeland condition, but it may be a necessary reference if information on K derived from tilled cropland soils is to be transferred to rangeland conditions. In the future, perhaps a new reference plot should be defined for rangelands, particularly if its relation to a tilled cultivated plot could be defined.

Slope Length (L)

The USLE relationship for the increase of erosion with slope length is:

$$L = (\lambda/72.6)^m \qquad [6]$$

where L = slope length factor which is the ratio of soil loss from a slope length λ in feet to the soil loss from a 72.6 ft long slope in the same conditions and m = an exponent. The L factor is a measure of the effect of accumulated runoff with increased slope length on detachment by runoff and sediment transport capacity of runoff. This relationship was derived using data from plots that ranged in length from 36 ft to 630 ft (Wischmeier et al., 1958) as indicated in Table 2. Experimental values of m varied from 0 to 0.9 among several locations in the Eastern U. S. The recommended m for field application of the USLE ranges from 0.2 for very flat slopes to 0.5 for 5% and steeper slopes (Wischmeier and Smith, 1978).

The slope length exponent m apparently increases for storms, soils, slope lengths and steepnesses, cover, and management where rill erosion increases with respect to interrill erosion (Foster et al., 1977). Therefore, m varies from storm to storm as the amount and rate of runoff vary with respect to rainfall. Soils highly susceptible to rill erosion are likely to have a large m. Long and steep slopes generally cause increased rill erosion relative to interrill erosion; consequently m is greater for these slopes. Conversely, m is smaller where cover and management more effectively controls rill erosion than interrill erosion. However, a constant m is generally used in practice, except for the variation of m with slope for steepness from 0 to 5%.

TABLE 2. Length of slope data summary.[1/]

Location	Slope	Row direction	Cropping	Slope length	Length of record	Average exponent of L[2/]
	(%)			(ft)	(years)	
Zanesville, OH	12	Contour	C.corn	36,73,145	7	0.27
Clarinda, IA	8	U&D[3/]	C.corn	158,315,630	7	0.31
Clarinda, IA	9	U&D	C.corn	73,145	11	0.36
Bethany, MO	8	Contour	C.corn	73,145	10	0.36
Bethany, MO	10	U&D	C.corn	90,180,270	9	0.90
Dixon Sp, IL	5&9	Contour	C,W,L	35,70,140	8	0.39
Arnot, NY	18	Contour	C.corn	73,145	8	0.45
LaCrosse, WI	3-18	U&D	C.barley C,W,M	36,73	5 3	0.45
LaCrosse, WI	16	Contour	C.corn	36,73,145	6	0.50
Marcellus, NY	17	Contour	C,C,O,M, C,O,M	36,73,145	7	0.60
Hays, KS	5	U&D Contour	C.wheat	36,73,145	10 7	0.00
Temple, TX	4	U&D	C.corn	36,73,145	15	0.00
Tyler, TX	9	Contour	C.cotton	36,73,145	15	0.54
Guthrie, OK	7.7	U&D	C.cotton	36,73,145	25	0.68

1/ Wischmeier, W. H. 1956. Distributed at a joint SEA-SCS workshop held at Purdue University, Lafayette, IN.
2/ Exponent of L when fitted to 108 years of annual soil losses = .48.
3/ Legend: U&D - Rows up and down hill; C. - continuous cropping; C - corn, W - wheat, L - legume, O - oats, M - meadow.

Slope length limits for applicability of the USLE have not been precisely defined. Foster et al. (1981) suggested that the minimum slope length to which the USLE applies is about 15 ft. This conclusion was based on a comparison of the form of the USLE with that of a more basic erosion equation having separate terms for rill and interrill erosion. The USLE gives no soil loss for a zero slope length while fundamental analysis suggests a significant soil loss from raindrop impact.

The upper limit is even less clearly defined. The USLE slope length is defined as the distance from the origin of overland flow to the point where runoff reaches a well defined channel or to where slope steepness decreases enough for deposition to begin (Wischmeier and Smith, 1978). A defined waterway or channel may not be obvious on rangeland, especially if it is not

eroding. Thus, selection of a slope length value involves judgement which results in different values by different users when the USLE is applied to the same site. One opinion is that USLE slope lengths seldom exceed 400 to 500 ft (Dissmeyer and Foster, 1980), and if a longer value is used, conditions at the site should be reviewed carefully. Williams and Berndt's (1977) method of using contour maps to estimate slope length for complex areas is an objective technique useful in some situations.

The L factor is assumed to be primarily related to rill erosion and sediment transport by runoff. It presumably could be different for rangeland than for cropland if rill erosion relative to interrill erosion differs for the two situations. Without support of data or analysis, my opinion is that the L factor is the USLE factor that transfers best from Eastern cropland to Western rangeland.

Slope Steepness (S)

The slope steepness factor of the USLE is given by:

$$S = 65.41 \sin^2\theta + 4.56 \sin\theta + 0.0654 \qquad [7]$$

where θ = slope angle. The steepness factor is a measure of the effect of slope steepness on hydraulic forces from raindrop impact and runoff and their capacity to detach and transport sediment. Also, the factor is a measure of the effect of slope steepness on amount of runoff and surface storage for runoff and detached sediment. The relationship is based primarily on plot data from natural rainfall at LaCrosse, Wisconsin where slopes varied from 3 to 18% and is supported by limited data from other locations (Smith and Wischmeier, 1957). The relationship of soil loss to slope was different at Blacksburg, Virginia than at LaCrosse, Figure 1. A part of the reason for the difference is that runoff increased significantly with slope at LaCrosse while it was nearly constant for all slopes at Blacksburg. Slopes at Blacksburg ranged from 3 to 25%. Figure 1 also shows relationships proposed by Zingg (1940) and Smith and Whitt (1947; Neal, 1938). The USLE relationship, equation 7, is the parabolic equation in Figure 1. Mutchler and Murphree (1981) recently used 250 ft plots and simulated rainfall to evaluate the length and steepness relationship for slopes less than 1%. The steepness relationship also varies with cover, roughness, soil, and runoff (Lombardi, 1979), but the variation has not been defined for field application.

Many rangeland slopes exceed 20% or 25%, the upper limit of the data used to develop the S factor. This raises the question of, "Can the USLE be reliably applied to rangeland slopes greater than 25%?" If the factor relationship is in error, it likely overpredicts soil loss. Meyer et al. (1975) found that soil loss from interrill erosion did not increase greatly for slopes between 15 and 30%, the upper limit of their data. Storage of runoff and sediment and amount of runoff may not be greatly affected by slope on rangeland soils. If these effects are negligible, soil loss is assumed to vary with slope to a power of less than 1 (Foster and Meyer, 1972). The Zingg (1940) equation of $S = (\sin\theta/0.09)^{1.4}$ has been recommended for steep cropland slopes in the Palouse (McCool et al., 1977).

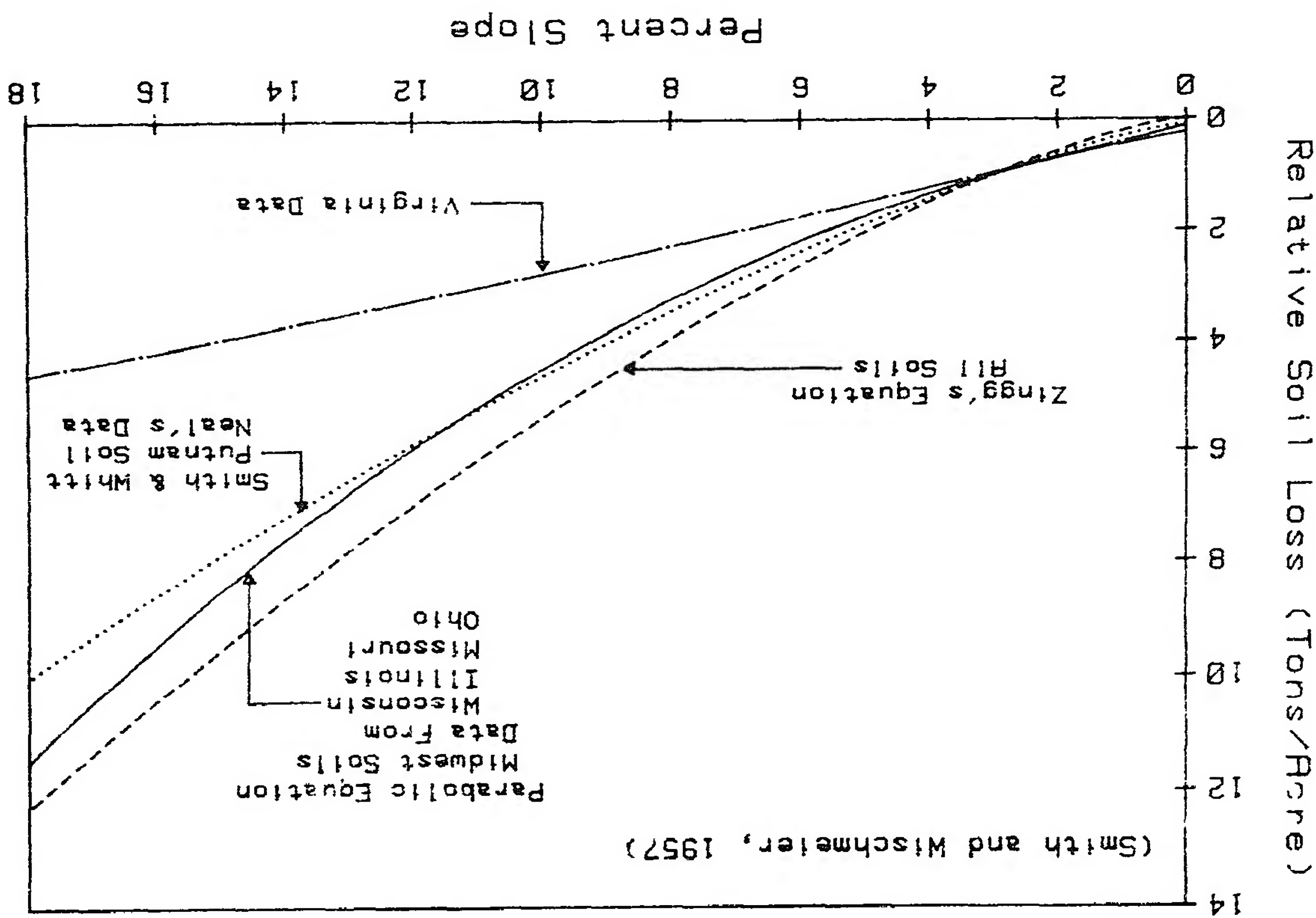

Figure 1. Variation of soil loss with slope steepness (Smith and Wischmeier, 1957).

The current recommendation is to use equation 7 for S with the recognition that soil loss from steep slopes may be over estimated. Sin θ should definitely be used rather than tan θ (% slope/100) in equation 7. Shear stress of flow down a vertical wall is finite as can be shown from solution of the Navier-Stokes equations. Sin θ is a direct result of such solutions; tan θ is not and besides tan θ gives an infinitely large shear stress for a vertical wall, an unrealistic result.

Irregular Slopes

Erosion depends on slope shape. Soil loss is greater from a convex slope than from a uniform slope of the same average steepness. Conversely, soil loss from a concave slope is less than that from a uniform slope of the same average steepness. A procedure (Foster and Wischmeier, 1974; Wischmeier and Smith, 1978) is available for applying the USLE to slopes where steepness, erodibility, cover, and management vary along the slope, provided changes along the slope do not induce deposition like that on the toe of concave slopes. The USLE cannot be used to estimate sediment transport through areas of widespread deposition; it is basically an erosion equation. The USLE irregular slope procedure is very rigorous, given the assumption that the USLE is a detachment limiting equation, rather than a transport capacity limiting equation (Foster and Wischmeier, 1974).

Cover-Management (C)

The cover-management factor C is a measure of the effect on erosion of cover and management that differs from the clean tillage on the unit plot. It measures: (i) the effect of canopy and ground cover on the hydraulics of raindrop impact and runoff; (ii) the effect of cover and management on amount and rate of runoff; (iii) the effect of cover and management on soil structure, organic matter, soil tilth, evapotranspiration, and other soil characteristics; (iv) the effect of a carry over from a previous land use when land use changes; and (v) the effect of roughness from tillage or other disturbances. Thus, the C factor is definitely more than just canopy and ground cover.

The cover-management factor C is evaluated from soil loss ratios, ratios of soil loss from a particular practice at a given crop stage on a given soil to that from a unit plot of the same soil. Soil loss ratio varies during the year with crop canopy, ground cover, primary tillage, seedbed preparation, and harvest. A value for C is a weighted soil loss ratio based on the distribution of rainfall erosivity over the year. Since the distribution of erosivity during a year varies with location, different C factor values are required for different locations for the same cropping practice.

Many soil loss ratios in Agriculture Handbook No. 537 (Wischmeier ahd Smith, 1978) are based on extensive data from natural runoff plots. However, those for conservation tillage and construction sites are based on data from rainfall simulator plots, most of which were 35 ft long. The values for undisturbed land are based on subfactor relationships for the separate effects of canopy, ground cover, soil consolidation, and plant roots (Wischmeier, 1975). These soil loss ratios, frequently applied to rangeland, have not been validated with extensive data specifically from rangeland conditions.

Nevertheless, they are based on sound principles and data for the individual subfactors.

All rangeland conditions are not covered by C factor values given in Agriculture Handbook No. 537. For example, roughness from root plowing or cattle trampling is not considered. Dissmeyer and Foster (1981) recently extended Wischmeier's (1975) subfactor approach to forest land. Estimated soil loss values agreed well with observed data indicating that the subfactor method can give good results especially for disturbed forest situations. Several of the factors considered by Dissmeyer and Foster (1981) may be applicable to rangeland.

The C factor is often the most important factor of the USLE. At a site, it is the only factor that a range manager may easily change to control erosion. Also, its effect on computed soil loss over its range of possible variation is greater than that of any other USLE factor. It is the factor that probably should receive first attention in a research program to adapt the USLE to rangeland.

Supporting Practices (P)

Examples of supporting practices on cropland are contouring, stripcropping, and terraces. The factor for supporting practices is the most difficult of the USLE factors to define and evaluate. Its values are probably more subject to error than are other factor values. Its main influence is through the effect of surface configuration on amount, rate, and flow direction of the runoff. Diversion of direct, downslope runoff to flow along the contour greatly reduces the detachment and transport capacity of the runoff. Significant deposition may result. Perhaps the effect of cattle trails on rangeland could be described by this factor. However, some USLE users prefer that such effects as those from cow trails be included in the C factor which may be more in keeping with USLE definitions (Wischmeier and Smith, 1978) since rangelands are seldom tilled in any direction. However, ridges from root plowing on the contour and pitting might be appropriate P factor effects.

INTERRELATIONSHIP OF FACTORS

The USLE factors are interrelated. For example, the slope length exponent, and hence L, depends on climate, soil, slope length and steepness, cover, and management. Thus, L is related to all other USLE factors. When the USLE was developed, available knowledge and application of the USLE for estimating average annual soil loss apparently did not warrant a more complex equation although interrelationships were recognized. However, if estimates of soil loss from specific storms, sediment yield from complex areas, and characteristics of eroded and transported sediment are required, more detailed models like CREAMS (Foster et al., 1980) must be used.

Other interrelationships involve factors used to describe a particular effect that could be included in more than one factor. The C factor includes soil effects --why not put these in the soil erodibility factor? Whether to account for surface rock fragments (erosion pavement) in the K or C is debated. In some cases, the final result is independent of the factor chosen to represent a particular effect. The chosen factor depends on tradition,

clarity, convenience, and ability to isolate and evaluate the particular effect with research data.

Although no runoff factor appears directly, the USLE does consider the effect of runoff on erosion. All USLE factors are related to runoff and to the interaction of natural rainfall with field conditions. For example, the effect of slope steepness for rough surfaces may be greater for variable natural rainfall than it is for long duration, high intensity, simulated rainfall. Data from rainfall simulators are not always directly transferable to natural conditions because of such interactions.

METRIC CONVERSION OF USLE FACTORS

Soil loss, erosivity, and soil erodibility factors have dimensions and units which require conversion to use the USLE in a metric system. Several conversion factors have been proposed. The ones by Wischmeier and Smith (1978) are for an older metric system and not the International SI system. Wischmeier and Smith's (1978) conversion factors and SI conversion factors published in a supplement to Agriculture Handbook No. 537, (USDA, 1981) give USLE factor values that are similar to those in the customary U. S. system. Since USLE values are often written without units, charts and tables of USLE values in U. S. customary units can be easily confused with similar charts and tables in SI units if the magnitude of values for R and K are similar in the two systems of units. Therefore, Foster et al.* proposed SI conversion factors that give factor values greatly different from values in U. S. customary units. Figures 2 and 3 are the erosivity (R) map and soil erodibility (K) nomograph based on conversion factors from Foster et al.*

Mitchell and Bubenzer (1980) proposed that charts and tables not be changed so that R and K values in U. S. customary units could be retained. They interpet R and K as coefficients from a dimensionally nonhomogeneous regression equation where dimensions have little or no significance. Computed soil loss would be converted to metric units in a final computation. This system requires that either values for R and K would be determined in convenient metric units and then converted to U. S. customary units or that basic data used to determine R and K be converted to U. S. customary units. A major disadvantage of their proposal is the continuance of a dual system of units.

SENSITIVITY OF USLE FACTORS

Computed soil loss from the USLE is more sensitive to change in some factor values than others. For example, the relative change in computed soil loss is less than the relative change in slope length, especially when the slope length exponent is 0.2. Soil loss from a 1000-ft slope length does not differ greatly from that from a 2000-ft slope length when both are on a 0.5% slope. The converse is true for the steepness factor. The relative change in computed soil loss is greater than the relative change in slope steepness.

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* Foster, G. R., D. K. McCool, K. G. Renard, and W. C. Moldenhauer. 1981. Conversion of the Universal Soil Loss Equation (USLE) to SI Metric Units. Submitted to J. of Soil and Water Conservation.

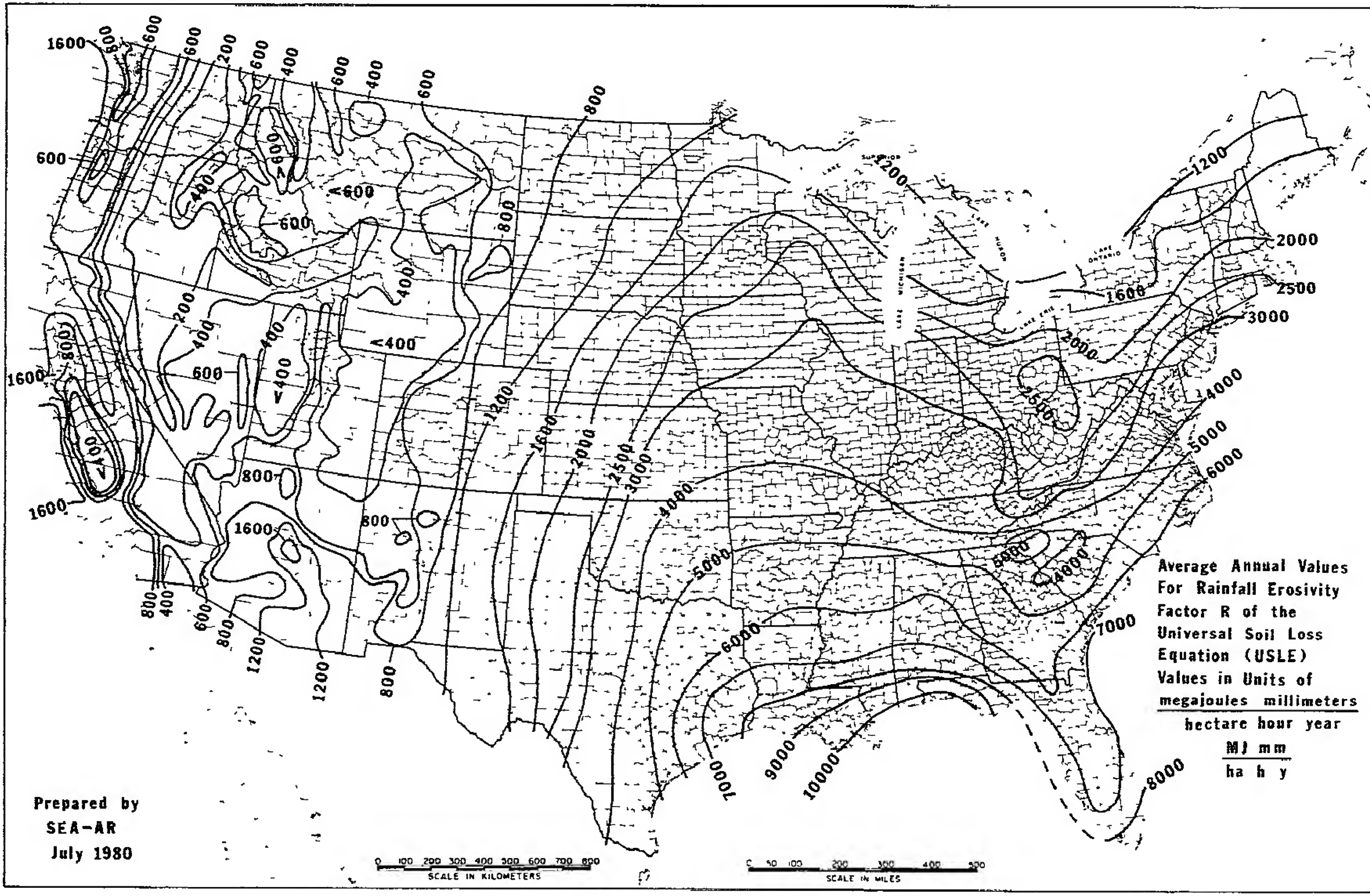

Figure 2. Average annual values for rainfall erosivity factor R in SI Metric Units.

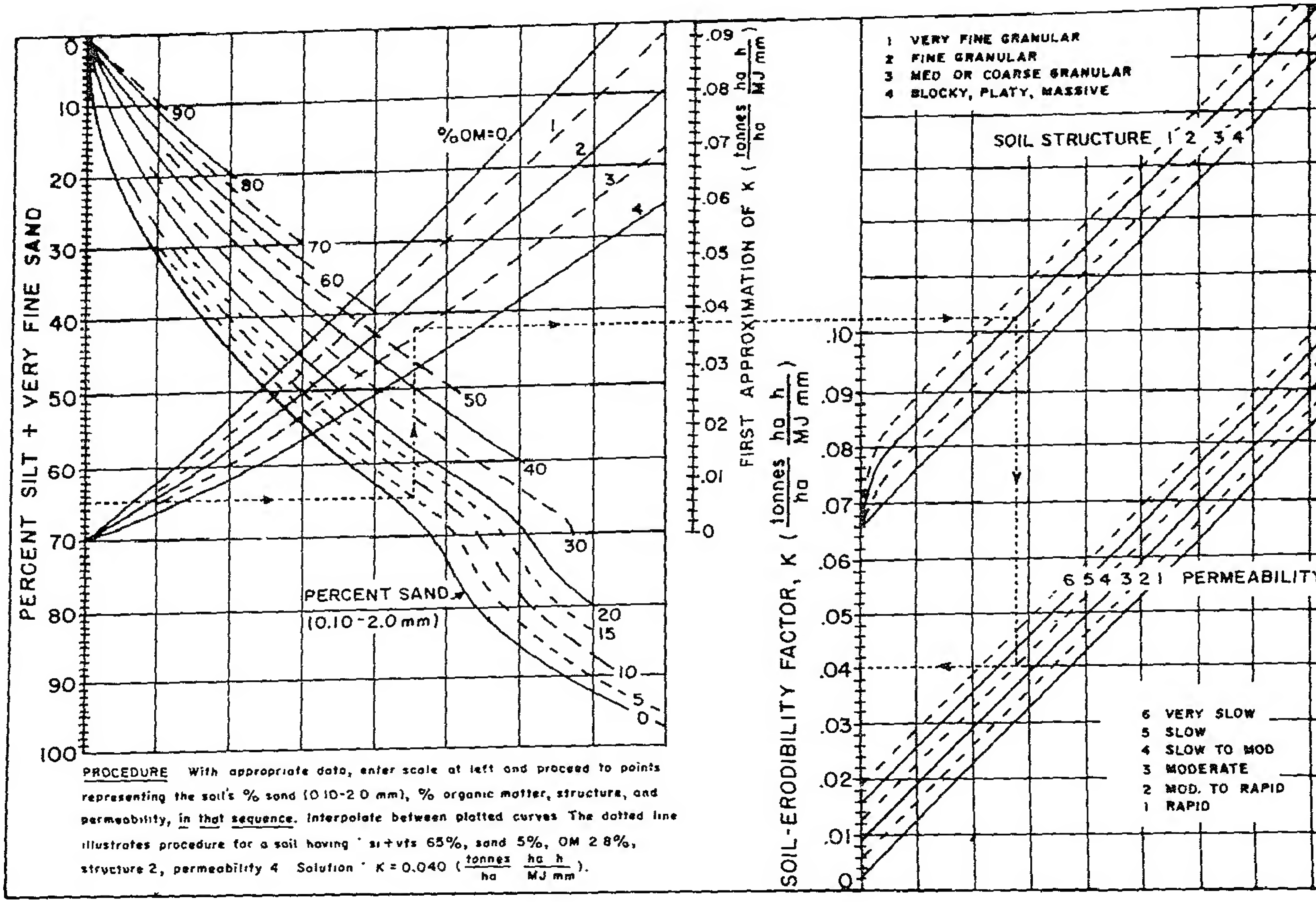

Figure 3. Soil erodibility (K) nomograph in SI Metric Units. Adapted from Wischmeier and Smith (1978).

Consequently, a value for slope steepness should be selected more carefully than slope length.

Soil loss ratio varies much more rapidly with ground cover at low percentages of ground cover, the normal condition on many rangelands, than at high percentages of cover. Canopy is unimportant for dense ground cover, but it is a major factor when ground cover is nearly bare and canopy is dense and near the ground. Values for soil loss ratio, and hence C, have the greatest relative range of the USLE factors. Certainly C is the most important factor for comparison of practices at a location.

Factors R and K can be evaluated precisely from charts and maps. This does not mean that these factors are free of error. Indeed, the error in these factors, especially R in the Western U. S., probably exceeds the error in L, even though determination of a value for slope length may be imprecise and variable among individual evaluators.

APPLICATION OF USLE

The USLE is primarily used as an inventory tool to assess sheet and rill erosion rates on agricultural land under current management, and as a guide in selecting practices to control sheet and rill erosion to a rate less than some soil loss tolerance. The USLE is a powerful tool in these roles. It should also be useful in these ways for rangeland applications (Johnson et al., 1980), although its estimates will likely not be as accurate for erosion on Western rangelands as for erosion on cropland in the Eastern U. S. This favorable opinion of the applicability of the USLE to rangelands is not shared by all researchers (Trieste and Gifford, 1980).

The variability between observed soil loss and soil loss estimates with the USLE may be greater than desired. Part of the variability must be attributed to the data themselves. Soil loss from a carefully prepared plot may sometimes be as much as twice that from an adjacent identical plot for a specific storm. Such natural variability in the data emphasizes the need for well planned experiments having adequate replications.

Major relationships in the USLE follow well established trends, even though the adequacy of certain USLE features like lumping rill and interrill erosion and sediment transport may be argued. For example, erosion generally decreases as ground cover increases. The USLE reflects this general trend although it may be significantly in error for a specific site. New knowledge of erosion processes, better experimental techniques, and better ways of considering natural variability in the field must be developed for major improvements in either predictions for average annual soil loss or for soil loss from specific storms.

The USLE does not apply to all erosion and sedimentation processes that may be important on rangeland. For example, gully and wind erosion may be serious on some rangeland, but the USLE does not apply to these processes. Wischmeier (1976) identified several other limitations of the USLE.

NEW DEVELOPMENTS

New research is continually improving the factors for the USLE and extending it to new applications. Consequently, quideline manuals like Agriculture Handbook No. 537 (Wischmeier and Smith, 1978) soon become out-dated and may not contain all the information currently being used by agencies like the Soil Conservation Service, Forest Service, and Bureau of Land Management. Much of the research on the USLE is conducted by the Science and Education Administration -Agricultural Research (SEA-AR) of USDA. A partial list is given below of the SEA-AR reseachers most active in USLE research. Additional SEA-AR scientists are also conducting related research on erosion control measures, basic erosion mechanics, and new prediction techniques.

1. Cover and management factors for crops in the Corn Belt: W. C. Moldenhauer, Lafayette, IN and J. M. Laflen, Ames, IA.

2. Application of the USLE to crops and flat slopes in the Mississippi Delta: C. K. Mutchler, Oxford, MS.

3. Application of the USLE to surface mines: J. V. Bonta, Coshocton, OH.

4. Cover and management factors for disturbed forest lands: G. R. Foster, Lafayette, IN.

5. Deposition behind terraces and small impoundments: J. M. Laflen, Ames, IA and G. R. Foster, Lafayette, IN.

6. Application of the USLE to the Palouse Region: D. K. McCool, Pullman, WA.

7. Application of the USLE to rangelands: K. G. Renard, Tucson, AZ and C. W. Johnson, Boise, ID.

8. Characteristics of eroded sediment: L. D. Meyer, Oxford, MS and R. A. Young, Morris MN.

9. Gully erosion: R. F. Piest, Columbia, MO and W. C. Little, Oxford, MS.

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BLM'S INTEREST IN ESTIMATING EROSION AND SEDIMENT YIELD ON RANGELANDS

J. C. Chugg, soil scientist[1/]
C. J. Lovely, hydrologist[1/]

The Bureau of Land Management (BLM) administers approximately 170 million acres of rangelands in the eleven western states, not counting Alaska. Concern over accelerated erosion and deteriorated range and watershed conditions on public lands, now administered by the BLM, goes back at least to 1934 with the passage of the Taylor Grazing Act.

The Act's purpose was "To stop injury to the public grazing lands by preventing overgrazing and soil deterioration, . . ." The Act, still in effect today, also authorized the Secretary of the Interior to continue the study of erosion and flood control. Forty-four years later in 1978, the Public Rangelands Improvement Act (PRIA) was passed with the purpose of improving range conditions. Within this Act it states:

"The Congress finds and declares that:

1) vast segments of the public rangelands are producing less than their potential for livestock, wildlife habitat, recreation, forage, and water and soil conservation benefits, and for that reason are in unsatisfactory condition;

2) . . . .

3) unsatisfactory conditions on public rangelands present a high risk of soil loss, desertification, . . . contribute significantly to unacceptable levels of siltation and salinity in major western watersheds . . ."

Congress, therefore in 1978 established and reaffirmed a national policy and commitment to inventory and identify current conditions and trends of public rangelands as required by the Federal Land Policy and Management Act of 1976. These inventories are to be kept current on a regular basis to reflect changes in range conditions.

1/Division of Rangeland Management, Bureau of Land Management, Department of Interior, Washington, D.C. 20240.

These laws and policies established by Congress from 1934 all the way up to the current year's appropriations bill necessitates that the BLM inventory and monitor rangeland conditions and trends. In order to do this, we must be able to:

1) access current erosion conditions and trends;

2) quantitatively determine current erosion and sedimentaton rates;

3) predict future rates based on various proposed management schemes, primarily implementation of grazing systems;

4) monitor erosion and watershed conditions to detect changes over time related to management activities;

5) we must also be able to differentiate between accelerated and natural (geologic) erosion in order to identify where to focus our management efforts and allow us to set practical management goals.

We currently have a third order soil inventory program in progress which is scheduled to be completed on all public lands by 1990. The new administration will likely cut back our ability to meet this goal and we may have to settle for a fourth order survey on some areas and possibly no survey on others.

The present soil survey program is part of the Bureau's Soil, Vegetation Inventory Method. These inventories, as presently being conducted, do not provide us with all the specific information necessary to quantitatively determine current and predict future erosion and sediment rates. The Bureau has an existing inventory procedure which qualitatively assesses current erosion conditions, Soil Surface Factor (SSF).

We are in the process of evaluating SSF and putting together information on other methods such as USLE and PSIAC which could be used to inventory and monitor erosion and sedimentation from western rangelands administered by the BLM.

The Bureau's field watershed specialists should be using the best available methods for their situation and locality. In order to do so the principles, procedures, capabilities, and limitations of these methods must be clearly and fully understood by the field specialist.

It should be obvious, now, why we are supporting attending and deeply interested in this workshop on Estimating Erosion and Sediment from Rangelands.

We encourage the participants of this conference to have a highly productive week.

Please keep in mind that the BLM, one of the biggest user groups for the practical application of erosion and sediment estimation procedures on rangelands, is continuously making management decisions on the 170 million

acres of rangelands it administers. These decisions are and will continue to be made and implemented on the best available information at the time, with or without, a sound technical analysis of erosion and sediment conditions.

The BLM needs positive recommendations on the best and most practical methods available to answer today's questions, which we fully anticipate will be among the accomplishments of this workshop.

USE OF EROSION MODELS ON WESTERN RANGELANDS

Karl A. Gebhardt, BLM hydrologist[1/]

BACKGROUND

Soil loss and sediment yield equations have received greater use on western rangelands in recent years largely because of the emphasis on quantitative impact analysis. This paper emphasizes the use of soil loss equations but most of the discussion can be applied to all types of erosion equations. The principle increase in the Bureau of Land Management's (BLM) use of the soil loss equations is due to the grazing environmental impact statement (EIS). Court action has required the BLM to place increased emphasis on quantification requirements for assessing impacts. The BLM, when dealing with watershed impacts, has interpreted the requirements as meaning numerical descriptions of soil loss. The available soil loss equations (Universal Soil Loss Equation, Musgrave) have been used in many EIS's to estimate existing soil loss and to predict soil loss due to changes in vegetative cover. The final product in many grazing EIS's appeared as shown in Table 1.

TABLE 1. TYPICAL SOIL LOSS PRESENTATION IN THE EIS

GRAZING ALLOTMENT	SOIL LOSS (TONS/ACRE) ANNUAL PRESENT	ALTERNATIVE A*	ALTERNATIVE B*
Jones Mountain	1.12	0.78	1.75
Red Creek	3.25	0.51	4.31
Sheep Dip	2.96	2.57	3.05

*ALTERNATIVE A could represent a "no grazing" proposal.
*ALTERNATIVE B could represent a "maximum grazing" proposal.

Early authors of the EIS failed to explain the limitations of the reported soil loss values. This resulted in some managers placing too much validity on the estimates. In a few cases the manager selected one alternative over another because the analysis showed a lower soil loss value with that alternative. However, differences in soil loss estimates were too small to be considered significant.

[1/] Idaho State Office, USDI, Bureau of Land Management, Box 042, Federal Building, 550 W. Fort St., Boise, Idaho 83724

Later efforts utilized the Modified Universal Soil Loss Equation, Williams and Berndt (1972), where Hekman and Fogel (1979) applied stochastic event-based precipitation records for predicting sediment yield as a function of runoff. The model was developed for the BLM expressly for the assessment of hydrologic impacts of grazing management programs.

The BLM's Boise District in Idaho recently completed the Owyhee Grazing EIS, BLM (1980) where the Musgrave (1947) soil loss equation was used in the impact analysis. Soil loss information was compiled by soil mapping unit then combined to represent soil loss on a grazing allotment basis. (The grazing allotment is a combination of pastures that compose the basic unit for grazing administration). Included in the data presentation were estimates of present soil loss rates and predicted rates for six alternative management schemes. In addition, estimates were made to represent soil loss under the best and worst vegetation conditions possible. Table 2 is a sample of data presented in the Owyhee EIS. The format shown allows a manager to compare various management schemes with the existing situation and sets them in perspective with endpoints given by the best and worst conditions.

TABLE 2. SOIL LOSS TABLE FROM OWYHEE GRAZING EIS, BLM, (1980)

Present and Projected Annual Erosion Rates

Allotment No.	Excellent Condition Best Possible Cover ton/acre/year	Present Condition ton/acre/year	Alternative* Proposed Action	1	2	3	4	5	Worst Possible Condition No. Plant or Litter ton/acre/year
450	0.65	0.85	24	22	12	24	24	22	2.58
500	0.32	0.45	8	19	0	12	5	0	1.12
501	1.86	2.41	7	19	0	12	5	0	3.88
502	1.72	2.21	0	19	7	12	0	-12	4.24
503	0.69	1.01	7	19	12	12	5	0	3.81
505	1.49	1.89	12	19	21	21	10	21	8.48
506	0.84	1.19	7	19	0	12	5	0	5.20
507	1.18	1.57	7	17	0	12	5	0	6.81
508	0.99	1.32	12	19	7	22	10	12	4.14
509	1.38	1.70	12	18	18	18	10	18	8.35
513	0.42	0.62	0	21	0	13	0	0	1.48
514	0.42	0.50	0	17	0	12	0	0	1.70
515	1.48	1.87	7	18	12	12	7	22	7.77

*Shown as percent change from present condition

Other BLM applications of soil loss equations to date have included evaluation of land treatment activities, road construction, mining and construction disturbance and off-road vehicle use. The most useful applications of erosion equations are in determining future land uses, assessing present use and evaluating corrective strategies. Unfortunately, misuse and overextension of the equations in some instances have presented management with a false sense of security. The technical specialist must convey the limitations of erosion data, and management must become more knowledgeable of the erosional processes. This would greatly increase the credibility of many management decisions.

LIMITATIONS

Limitations of the soil loss estimates should be explained to avoid misuse in application. Some basic limitations can be derived from a thorough understanding of the equations' development and evolution. "Predicting Rainfall Erosion Losses" Wischmeier and Smith, (1978) provides some good overview of soil loss equation history. Experimental designs and methodologies used to arrive at and evaluate other equations can be found in their respective original publications.

Wischmeier and Smith (1978) present a number of basic limitations. For example, USLE estimates are generally most accurate with slope lengths of less than 400 feet and slopes from 3 to 18 percent having consistent cropping and management systems. Since the USLE is empirically derived, these limitations obviously do not favor wide application to rangelands without extensive field validation. Rangeland limitations of soil loss equations can be quite extensive. For example, many soil loss equations were developed for use on croplands which usually have homogenous soil characteristics, adequate precipitation data, gentle-regular slopes, consistent vegetative cover and tillage practices. Conversely, rangelands seldom have any of the above characteristics which complicates the rangeland soil loss estimate.

Each factor in the USLE or any other equation should be carefully studied as to its origin. For example, the cover and management (C) factor for the USLE was derived for use on rangelands based on extensions of the cropland cover factor. The rangeland "C" factor was not developed from extensive soil loss measurements as was the cropland cover factor. Wischmeier and Smith (1978) discuss the "C" factor as being dependent on three zones of surface influence: (1) vegetative cover in direct contact with the soil surface; (2) canopy cover and (3) residual and tillage effects. Figure 1 represents the effects of the canopy cover, ground cover, and condition of cover on the USLE cover factor for a typical brush rangeland extrapolated from Table 10 in Wischmeier and Smith (1978). The figure indicates that a relatively small change in percent ground cover can cause a large change in the cover factor. For example, a 10 percent change in the ground cover can result in a 15 to 30 percent change in the cover factor. Assuming all other factors in the USLE remain constant, this would result in a 15 to 30 percent change in the soil loss estimate.

The next obvious limitation of the cover factors' use is the validity of ground cover estimates. The BLM probably collects as much rangeland vegetation data as any group in the United States. The data is collected on a "range-site" basis in order to reduce the number of samples required. The range-site technique stratifies similar vegetation-soil complexes and provides information related to plant community structure, ecological potential, ecological condition, etc. Among the data collected are the basal cover values and three levels of canopy. There is no compiled information on cover variation within range sites but conservative guesses would place the variation in the 10-plus percent range. This indicates that for a given piece of public land with existing vegetation data, soil loss estimates can be expected to have a variation of at least 15 to 30 percent over similar range sites in the same ecological condition. This

indicates the USLE and the equations may be well-suited for use in comparative analysis, however, use of the estimates as absolute values must be done cautiously. Wischmeier and Smith (1978) state that: "Soil losses computed with the USLE are best available estimates, not absolutes".

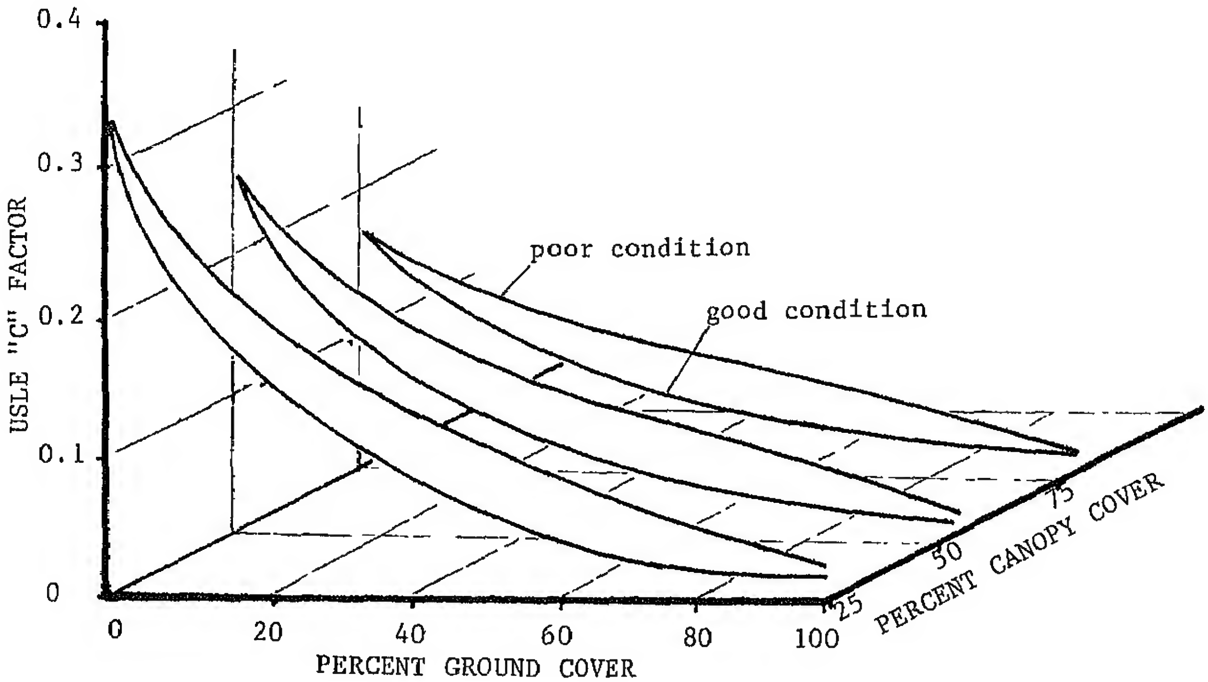


FIGURE 1. USLE "C" FACTOR FOR TYPICAL RANGELANDS ADAPTED FROM WISCHMEIER AND SMITH (1978) TABLE 10

Another limitation entering into the "C" factor dilemma is the prediction of future vegetative cover. Presently there is no widely used methodology that relates use, climate and other conditions to vegetative cover response. Unpublished data from the Reynolds Creek Experimental Watershed (Northwest Watershed Research Center) allows some comparison of cover values at varying range sites and under high, moderate and low grazing levels. Vegetative cover changes in excess of 10 percent were uncommon in the Experimental Watershed's data. This indicates that for range sites similar to Reynolds Creek, under reasonable grazing intensities, cover changes probably will not be greater than 10 percent. This transforms into a maximum USLE predicted soil loss change of 15 to 40 percent.

The value of the Reynolds Creek data and its application in southwestern Idaho became apparent to BLM specialists when they were requested to predict future vegetative cover changes. By no means did the data give some magical formula for predicting vegetative cover changes, but it did set some reasonable limits as to what to expect. Others intending to use soil loss estimates for predictive applications should place a great deal of effort in "C" factor selection and should try to support their conclusions with some field data.

Another problem includes using an erosion model on an area whose erosional processes are not within the design limitation of the equation. Examples can be seen where rainfall erosion equations were utilized to assess erosion in areas where rainfall erosion was uncommon. Misunderstanding of erosional process criteria in any model can lead to grossly incorrect conclusions.

A brief word on definitions is appropriate here. Articles on erosion are increasing and with them is the misuse of terminology. The processes are complex enough without having to wade through an author's paper thinking he was describing sediment yield when in fact he was estimating soil loss. Most textbooks plus USGS and USDA publications have few conflicts in terminology and should be used for reference definitions.

Finally, those presenting soil loss data should include information on how accurate the estimates are. This would minimize the misinterpretation of soil loss data. It is the responsibility of the technical specialist to insure correct use and interpretation of erosion data.

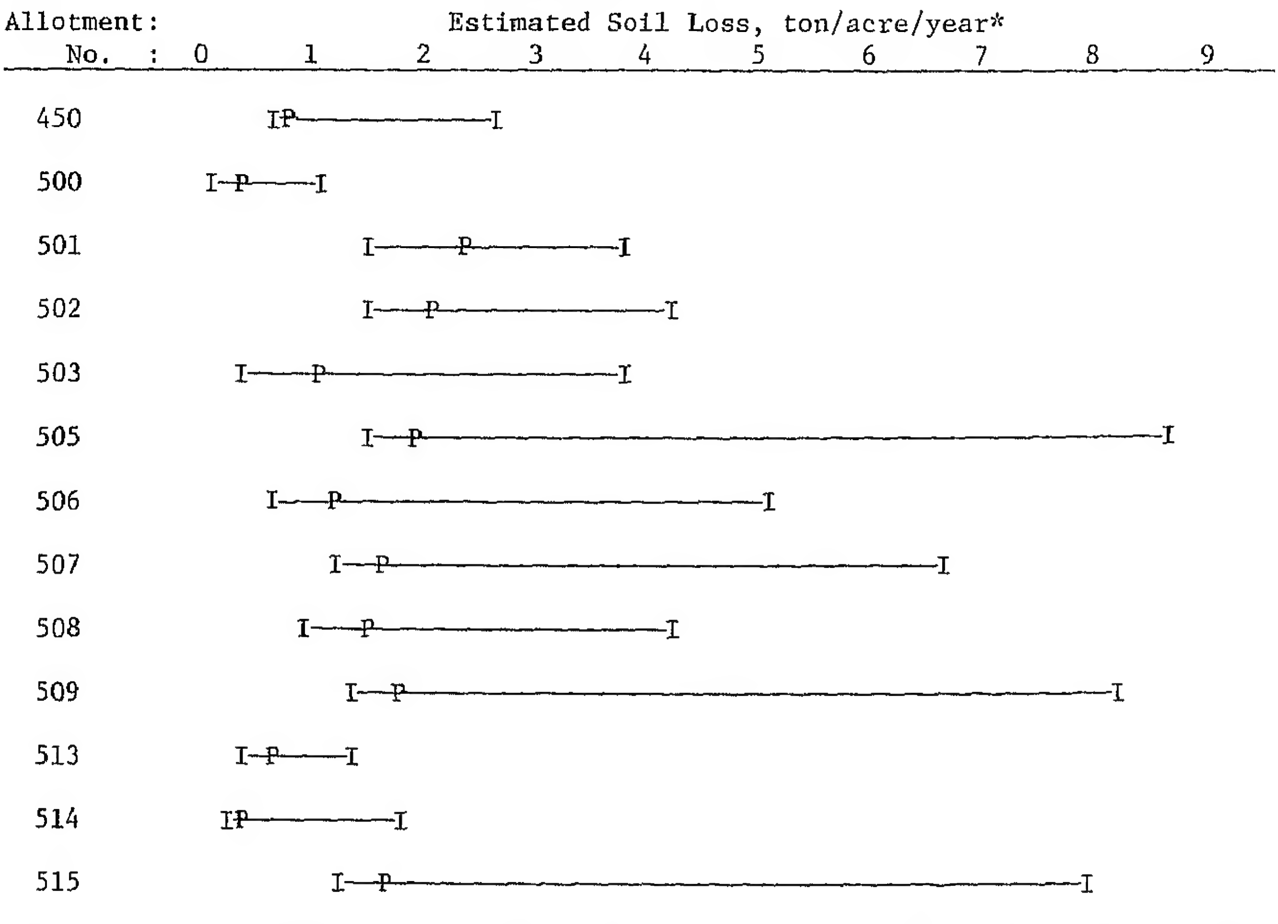
MANAGEABLE CHARACTERISTICS

A manageable characteristic is a factor that can be affected by management actions. In the USLE, the "C" (cover and management) and "P" (support practice) factors are the only two parameters of the equation that can be significantly affected by management. In the Musgrave equation, the "R" factor (cover) is considered the only manageable characteristic. In the Pacific Interagency Committee Procedure (1968) for estimating sediment yields, the ground cover and land use factors are the primary manageable characteristics.

A draft U.S. Forest Service procedure for predicting sediment yield Cline et al. (1980) utilizes estimates of natural sediment yields, sediment from management-induced surface erosion and sediment from management-induced mass erosion. This procedure places emphasis on manageable characteristics to a large degree. Similar systems appear in the USDA-Forest Service (1980) document, "An Approach to Water Resources Evaluation of Non-point Silvicultural Sources (WRENSS)," the USGS circular, "A Synoptic Approach for Analyzing Erosion as a Guide to Land-use Planning," Brown et al. (1979), and "Oregon's Procedure for Assessing the Impacts of Land Management Activities on Erosion-related Non-point Source Problems," Rickert et al. (1978). The latter two references are semi-quantitative but provide an excellent procedure for assessing manageable characteristics and erosional problems.

The importance of the manageable characteristics lies in the ability to estimate erosion responses to management treatment. Table 3 shows how the USLE or Musgrave soil loss estimates can be used to help a manager understand potential effects of manageable characteristics. Table 3 gives the relative endpoints and the expected results of the various alternatives. In addition, it alerts the manager to what the relative erosion sensitivity of each allotment is. For example, allotment 505 could have extremely high soil loss rates if improper management is applied, while allotment 500 is somewhat buffered to the effects of management actions. More effort is needed to develop presentation techniques that enable the manager to effectively utilize erosion information.

TABLE 3. SOIL LOSS DISPLAYED GRAPHICALLY



*"P" indicates present condition. Endpoints represent best and worst conditions possible. Data from BLM (1980).

APPLICATION

Application of available erosion methodologies must be geared toward solving problems associated with resource use. In order to arrive at an applied endpoint, the erosional processes need to be linked to problem identification, problem solutions and resulting resource use. For example, a typical problem could be stated as: What type of grazing management schemes can be implemented in order to maximize forage utilization without seriously affecting the soil and aquatic resource? The complexity of the question is great. Livestock grazing will affect the upland watershed causing changes in rates of soil loss. Impacts upon the stream environment can include the upland effects combined with the direct livestock use of the stream, its channel and adjacent vegetation. Upland effects, channel damage, removal of protective streamside habitat all will be important considerations in assessing effects upon the aquatic resource. It is extremely evident that erosion researchers must direct their work towards meeting the needs of those resources most affected by erosion.

Another example of needed application is soil loss tolerance. Agriculture research has identified this need in the past and has designed methods by which soil loss can be linked to productivity. This type of effort is needed for the rangelands to enable the assessment of long-term use and productivity. Simanton et al. (1980) has identified the need for considerable investigation into the hydrology-erosion-biotic relationship, which this author hoped to reiterate in this paper.

SUMMARY

Although erosion research is going in the right direction, more interchange is required between the researchers and those needing to use the research to solve management problems. More work is needed to include limitations of the data presented. Data presentation requires ingenuity to make erosional data meaningful and understandable. Those somewhat familiar with erosional processes must be careful not to abuse or misuse erosional models for application purposes. Those specialists dealing with research, development and application must look beyond their individual niche and consider the whole picture of erosional processes and their implications to various resource values. The erosion model must be designed for the needed application and be sensitive to changes in manageable characteristics.

ACKNOWLEDGEMENTS

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STATUS REPORT ON THE USE OF THE UNIVERSAL SOIL LOSS EQUATION BY THE BUREAU OF LAND MANAGEMENT

Richard J. Page, BLM Natural Resource Specialist[1/]

In accordance with legislative mandates, it is Bureau policy "to manage efficiently the basic resources of the public rangelands to improve and maintain their productive capability" USDI-BLM (1979). Controlling soil loss is an integral part of this management policy.

At present, soil erosion on Bureau administered lands is characterized through the Soil Surface Factor (SSF). The SSF places individual sites into erosion condition classes but does not provide a quantitative estimate of soil loss. No Bureau policy exists, as yet, on the use of the Universal Soil Loss Equation (USLE). Nevertheless, many Bureau personnel are using the USLE to predict soil loss resulting from site specific activities such as pipeline construction, mineral exploration, and mining. In these situations, conditions before and after the proposed actions can be compared. While there may be some dispute over the absolute values obtained with the USLE, the relative magnitude of soil loss provides a valuable comparison.

Plans are underway in the Susanville, California District to use the USLE in an expanded rangeland monitoring program. Changes in ground cover and corresponding changes in predicted soil loss will be used to assess trend in rangeland condition. Actual soil losses from three small watersheds (approximately 1,000 acres ea.) within the monitoring area will be measured for comparison with the predicted values.

In certain cases, the USLE estimates appear to be less useful. Soil loss from logging actions (skid roads, ditches, and cut slopes, etc.) in the Western Oregon forests is not easily evaluated with the USLE. Additional problems exist in determining soil loss from broad landscape areas. Existing soil information on Bureau lands is often inadequate to determine the necessary USLE parameters.

Our experience with USLE in the BLM has shown that slope lengths are generally overestimated. Furthermore, surface rock cover needs to be considered along with that provided by vegetation and litter. These considerations appear to be especially important for ecological sites with shallow soils and steep slopes. In such cases, estimated soil loss can far exceed reasonable values.

Last year the SCS and the BLM in Utah cooperated in a study to evaluate some of the effects of rock cover and complex slope conditions, Erickson (1980).

1/ Utah State Office, Bureau of Land Management, U.S. Department of the Interior, Salt Lake City, Utah 84111

The first study area included mainly grass cover and showed little evidence of past erosion. Slope varied from 11 percent to 28 percent. Soil losses were calculated for specific slope segments; rock fragments were incorporated to (a) adjust the C factor, (b) adjust the K factor, USDA-SCS (1979), and (c) adjust both C and K factors.

Average soil loss estimates are as follows:

Modification to USLE	Soil Loss (T/Ac)
- C factor adjusted for rock	.6
- K factor adjusted for rock	1.3
- C and K factors adjusted for rock	.4

On steeper segments where only the K factor was adjusted for rock fragments, soil loss estimates were thought to be too high compared to actual conditions. Estimates varied from 1.6 to 3.3 T/Ac while actual losses appeared to be well below 1 T/Ac. Soil loss estimates were quite similar when rock fragments were used to adjust either cover or cover plus the K factor. Visually, either of these two soil loss estimates seemed reasonable.

The second study area included sagebrush, grass, and forb cover and showed signs of considerable soil erosion. A 50-pace transect was run across the area stopping at each fifth pace to determine slope length and steepness.

Soil loss was then calculated using (a) the average of the 10 length and steepness measurements, and (b) the overall slope length and steepness from top to bottom. Soil series and ground cover were considered to be similar throughout the study area; C and K factors were adjusted for rock fragments as indicated.

Soil loss estimates for the second area are as follows:

Modification to USLE	Soil Loss (T/Ac)
Average slope length and steepness with:	
- C factor adjusted for rock	4.1
- K factor adjusted for rock	4.1
- C and K factors adjusted for rock	3.0

Modification to USLE	Soil Loss (T/Ac)
Overall slope length and steepness with:	
- C factor adjusted for rock	6.4
- C factor adjusted for rock	7.7

As evidenced, soil loss estimates were notably higher using the overall slope length and steepness measurements. As for rock fragments, adjustment of the C factor or both the C and K factors gave generally lower soil loss estimates regardless of the approach to slope length and steepness.

Few definite conclusions can be drawn from a limited study such as this. Clearly, however, slope determinations alone can account for a wide range of soil loss estimates. Similarly, the inclusion of rock fragments can produce different results. We, in the BLM, must recognize the effects of alternate approaches in applying the USLE, since the results will affect our multiple use management decisions.

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THE USLE RAINFALL FACTOR FOR SOUTHWESTERN U.S. RANGELANDS

J. R. Simanton and K. G. Renard[1]

INTRODUCTION

Air-mass thunderstorms, occurring primarily during the summer months of July through September, dominate the rainfall/runoff/erosion relationships in much of the rangeland areas of the Southwest (for high mountain ranges, snowmelt is significant). To estimate the erosion associated with such areas, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is being used to reflect the climatic variability and the potential erosion due to raindrop impact. The air-mass thunderstorms in the region are typically highly variable in both time and space, of limited areal extent, and of short duration. About 70% of the annual 11 in and 75% of the annual 12 in of precipitation occurs during this summer thunderstorm season in southeastern Arizona and central New Mexico, respectively.

The Southwest Rangeland Watershed Research Center of USDA's Science and Education Administration has conducted research on several experimental watersheds in Arizona and New Mexico which has included the use of numerous recording raingages (Fig. 1). Data from these locations are used in this paper to compute the rainfall erosion index (product of the kinetic energy and 30-min maximum intensity) to illustrate the extreme temporal and spatial variability of the USLE rainfall erosion index (EI). Finally, a method is proposed for estimating the average annual rainfall erosion index (R) when data are not available but when the 2-yr frequency 6-hr duration precipitation can be estimated.

Temporal Variability

Extreme temporal variability of EI on the four areas studied is found annually, seasonally, and within a single storm (Renard and Simanton, 1975, Simanton et al., 1980). Total annual EI for one long-term rainfall record from each of four different watershed locations is plotted versus probability in Fig. 2. The steepness of the fitted lines indicates extreme annual variability. This annual EI variability is even more dramatic when compared to the annual precipitation variability (Fig.3). For example, the coefficient of variability (CV) for rainfall is 0.27, whereas that for EI is 0.67.

Average annual rainfall erosion index (R), the coefficient of variability (CV), and percent of annual EI contributed by summer storms at each of the

[1] Hydrologist and Hydraulic Engineer, USDA-SEA-AR, Southwest Rangeland Watershed Research Center, 442 East Seventh Street, Tucson, AZ 85705.

gages shown in Fig. 2 are listed in Table 1. Seasonal EI variability is even more pronounced when summer EI values are plotted versus probability (Fig. 4). The CV for only the summer storms' EI on Walnut Gulch is 0.74, whereas the CV is 0.67 for the annual rainfall EI. Summer thunderstorms are most important in rangeland erosion studies.

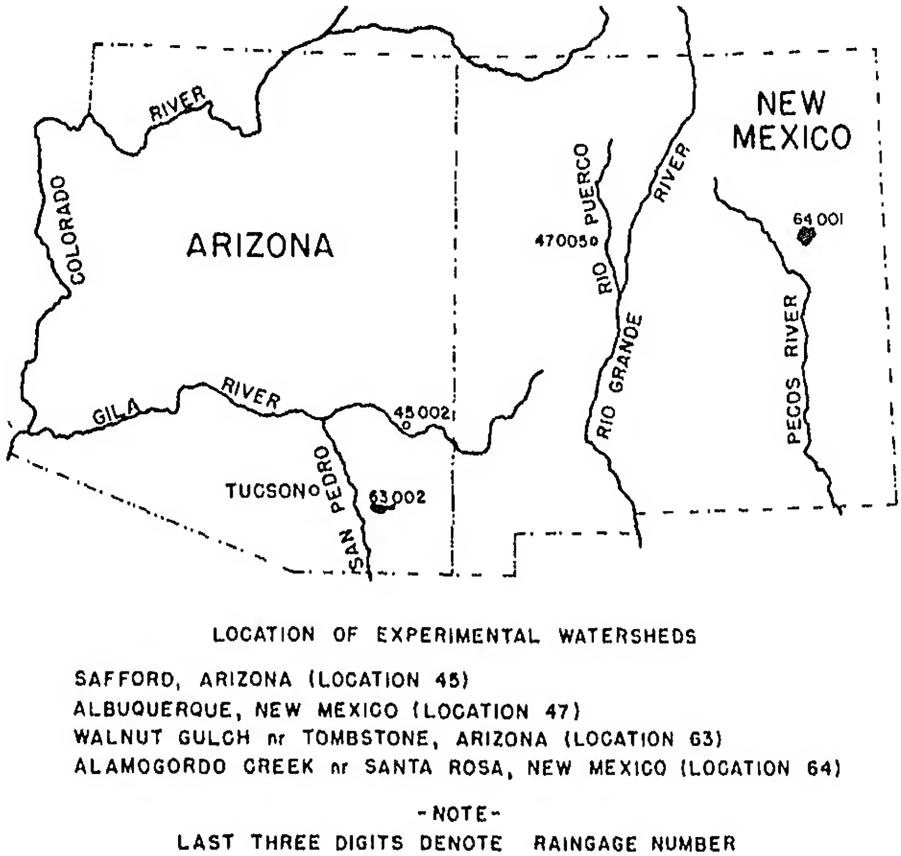

Figure 1.--Location map of the four experimental watersheds.

A single storm can contribute a large portion of the annual rainfall erosivity. For example, the largest storm within a year was observed to account for 76, 74, 66, and 85% of the annual EI for the Walnut Gulch (WG), Safford, Alamogordo Creek (AC), and Albuquerque (Albq) locations, respectively (Fig. 5). The bar graphs of Fig. 5 not only illustrate the largest storm contribution to the annual EI for each of the watershed locations but also exemplify the annual EI variability. We found, in a study conducted on small watersheds on WG, that the largest storm contributed, on the average over a 7-yr period, 58% to the annual soil loss. The average contribution of the largest storm to the annual EI for this same period was 41%. Also, as another example of the importance of a large storm, the maximum storm EI's at Safford in 1943, 1944, and 1961 were larger than the annual EI's for the remaining 22 yr of record. Similar results were found at the other locations. Although the USLE is not intended to estimate soil loss on a per-storm basis, this largest storm may be the most significant factor in annual soil loss.

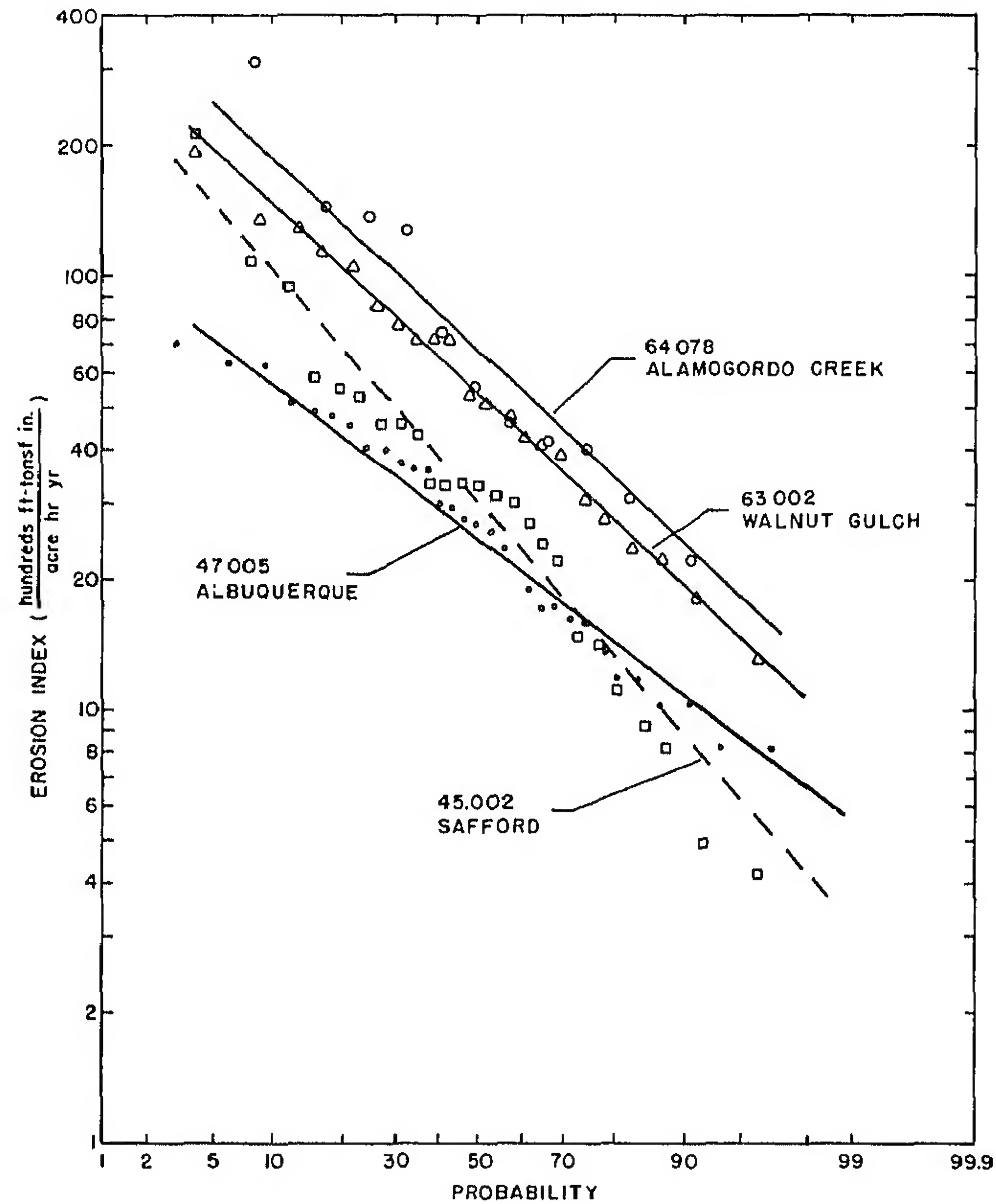

Figure 2.--Log-normal probability of erosion index for long-term annual rainfall records from each of the studied watersheds.

Table 1.— Average annual R factor, coefficient of variability, and percent summer contribution of four Southwestern U.S. watersheds.

Location	Average annual R	Coefficient of variability	Summer EI Contribution
			(% of annual)
WG	64	0.67	91
Safford	42	1.04	85
AC	81	0.83	93
Albq.	30	0.58	90

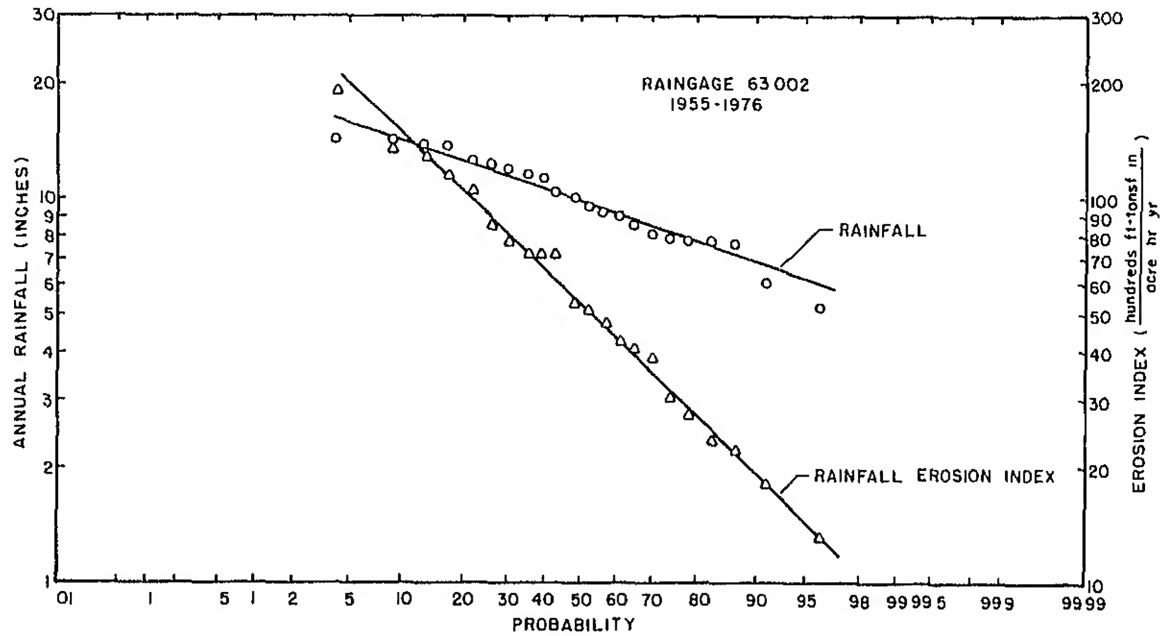

Figure 3.--Log-normal probability of rainfall and erosion index for one raingage on the Walnut Gulch experimental watershed.

Three storms were selected from the summer thunderstorm data from the WG and AC watersheds to illustrate the temporal EI variability within a single storm. The storm data are plotted in dimensionless form in Fig. 6. Because EI computation is based on maximum 30-min rainfall intensity, most of the EI units are derived from a relatively short, high-intensity portion of the storm. Thus, in thunderstorm dominated precipitation areas, such as the rangelands of Arizona and New Mexico, records from recording rain gages with depths for short time intervals must be used to compute storm EI. Standard rain gage data or hourly precipitation values may greatly underestimate EI. However, these are the type of data most widely available in the southwestern United States. Of the 280 reporting weather stations in Arizona, only 12% use recording gages, and data from these are generally available for only hourly depths. If these recording gages were evenly spaced throughout the state, each gage would represent the rainfall pattern of 3500 mi^2. Osborn et al. (1972) reported that to describe the rainfall patterns of the 58-mi^2 Walnut Gulch Watershed, 1000 gages would be needed to have a correlation of 0.9 between adjacent gages.

Total rainfall and EI from one raingage at each of the four watersheds were correlated to determine the feasibility of using a total rainfall term instead of energy-related rainfall factor in the USLE (Table 2). The results of this analysis are not encouraging. Wischmeier and Smith (1958) reported the correlation coefficient increased from 0.68 to 0.82 when they used EI rather than total rainfall for correlation with erosion data on a Shelby soil.

Table 2.—Correlation of total-rainfall and erosion index.

Location	r	n
WG (63.002)	0.79	19
Safford (45.002)	0.75	25
AC (64.078)	0.64	11
Albq. (47.005)	0.61	30

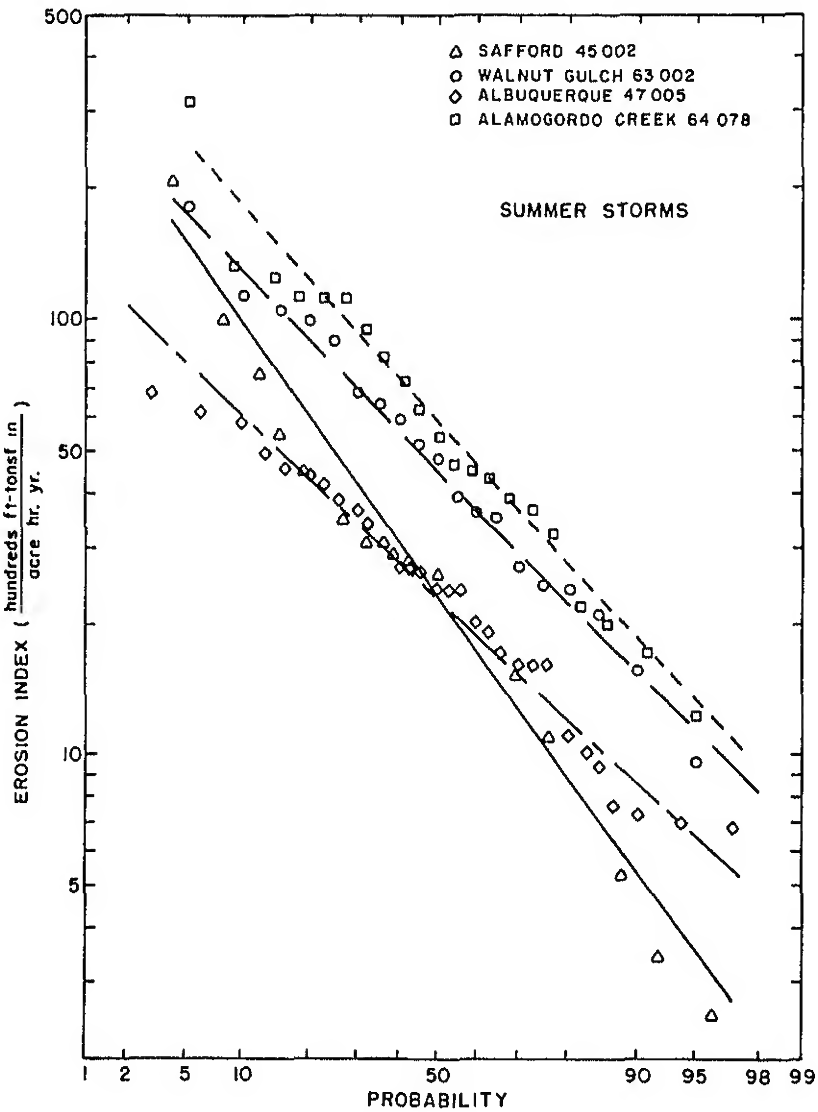

Figure 4.--Log-normal probability of erosion index for long-term summer rainfall records from each of the studied watersheds.

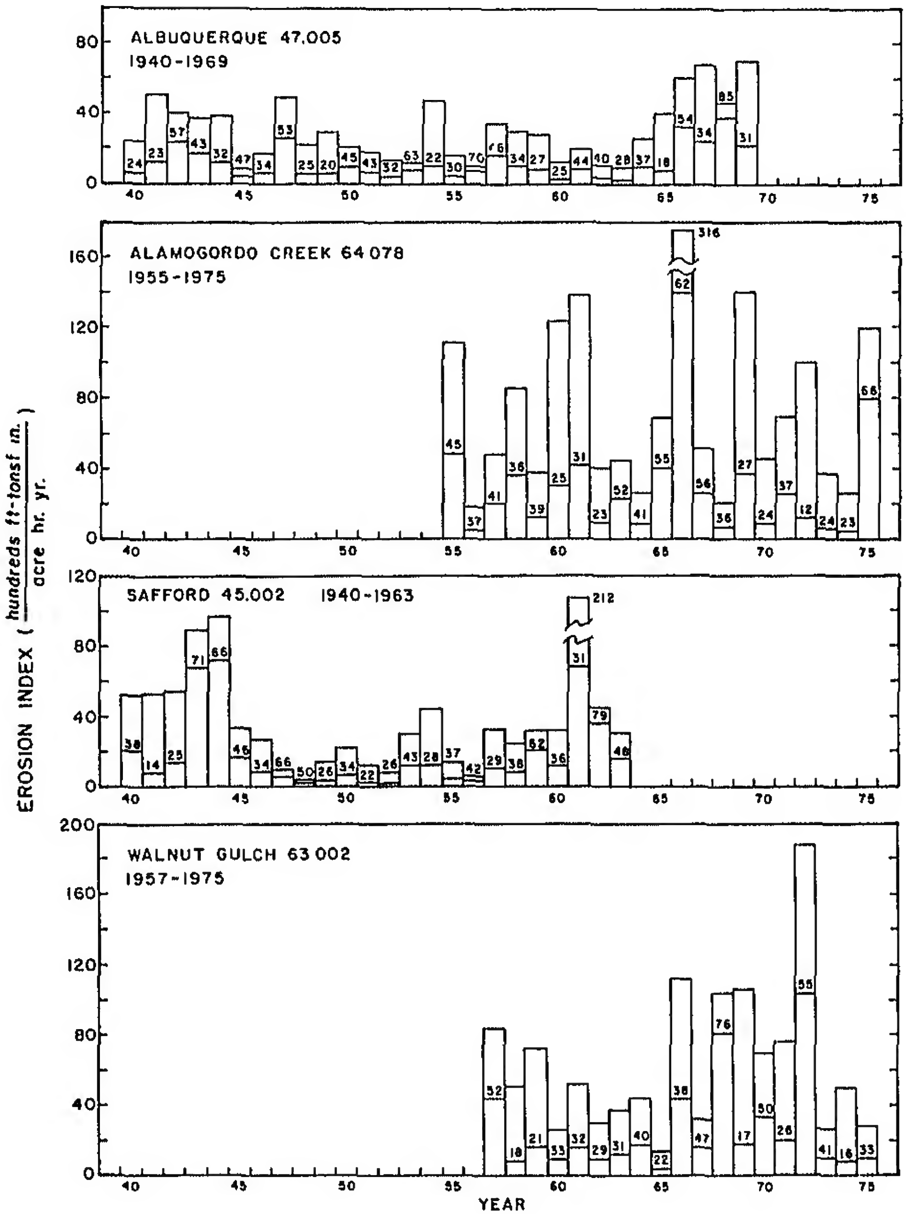

Figure 5.--Annual erosion index, largest storm-erosion index, and percent contribution of the largest storm to the annual erosion index (values in bars represent percent of annual contributed by largest storm).

Spatial Variability

Spatial variability of EI associated with thunderstorm rainfall can be illustrated using isoerodent maps for individual storms and years. The dense raingage networks of the WG and AC watersheds were used to produce the maps

shown in Figures 7, 8, 9, and 10. The July 22, 1964 storm on WG lasted less than an hour with almost 1.8 in of rain falling in 20 min at the storm center. The storm EI decreases from 100 near the storm center to about 30 in a radius of about 2 mi. Results are similar for most thunderstorms at this location.

The isoerodent map for the June 16, 1966 storm on the AC watershed illustrates single storm EI for one of the largest events recorded at this location. The storm lasted slightly over 2 hr and produced almost 3 in of rainfall in 30 min at the storm center. The EI varied widely with almost 260 units at the storm center to only 10 units 4 mi away.

Such spatial variability from individual storms leads to the expectation of extreme annual variability. Figures 9 and 10 illustrate the annual variability for WG and AC for the same years used to illustrate individual storm variability (1964 and 1966). In general, highs and lows of both precipitation and EI agreed for both areas, although EI unit per unit of rainfall differed. At the lowest annual rainfall depth on WG there were 3 EI units per in of

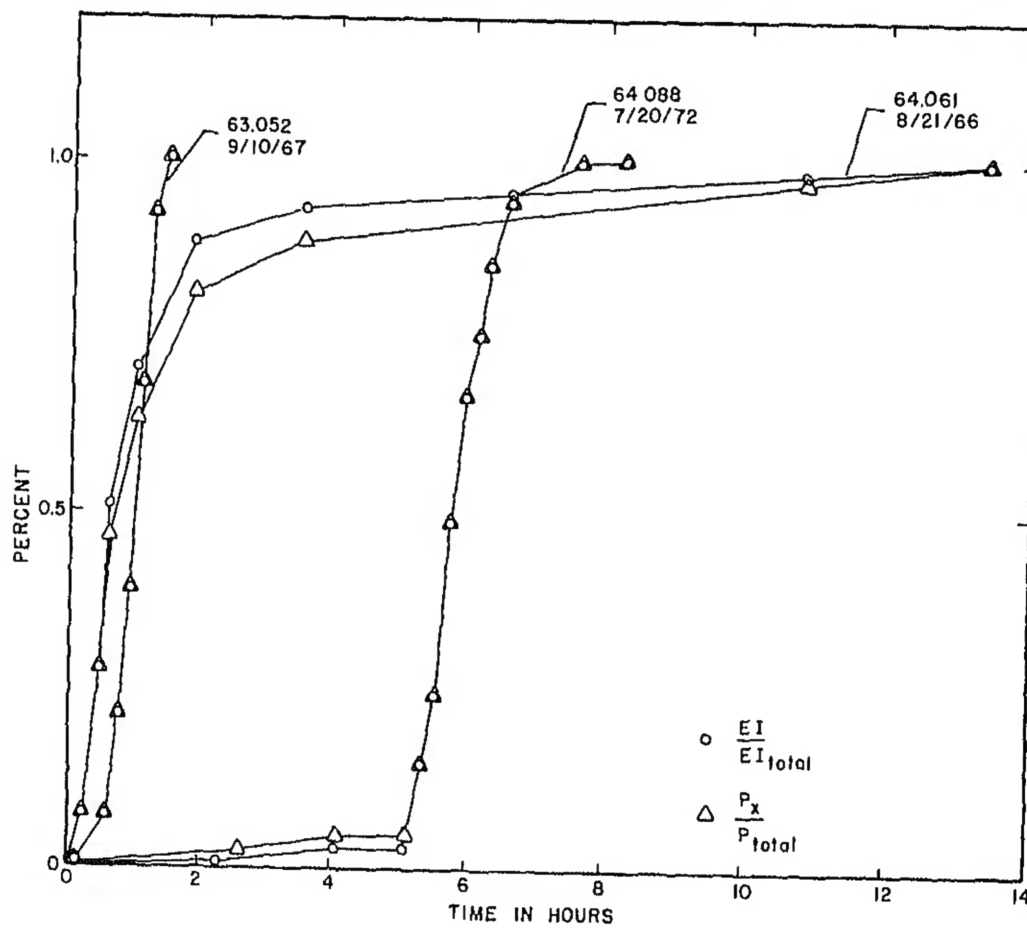

Figure 6.--Comparison of dimensionless precipitation and rainfall-erosion index for three select storms on Walnut Gulch (63.052) and Alamogordo Creek (64.008 and 64.061) (From Renard and Simanton, 1975).

precipitation, whereas AC had 6 EI units per in of precipitation. For the maximum annual rainfall depth there were 15 EI units per in rainfall on WG and 21 on AC. This points out that the record from a single gage yields a value for that point only and the results should not be extrapolated more than about a mile to estimate the erosion from a storm or for an individual year. For erosion studies being conducted on small watersheds in the Southwest, it is recommended that a recording raingage be located within 0.3 mi (Osborn et al., 1979).

Frequency Analysis

Analysis of southeastern Arizona rainfall data has shown that a log-normal distribution generally fits the data quite well (Reich and Renard 1981). The same has been observed for the rainfall EI. The 2-yr EI (50% probability) of

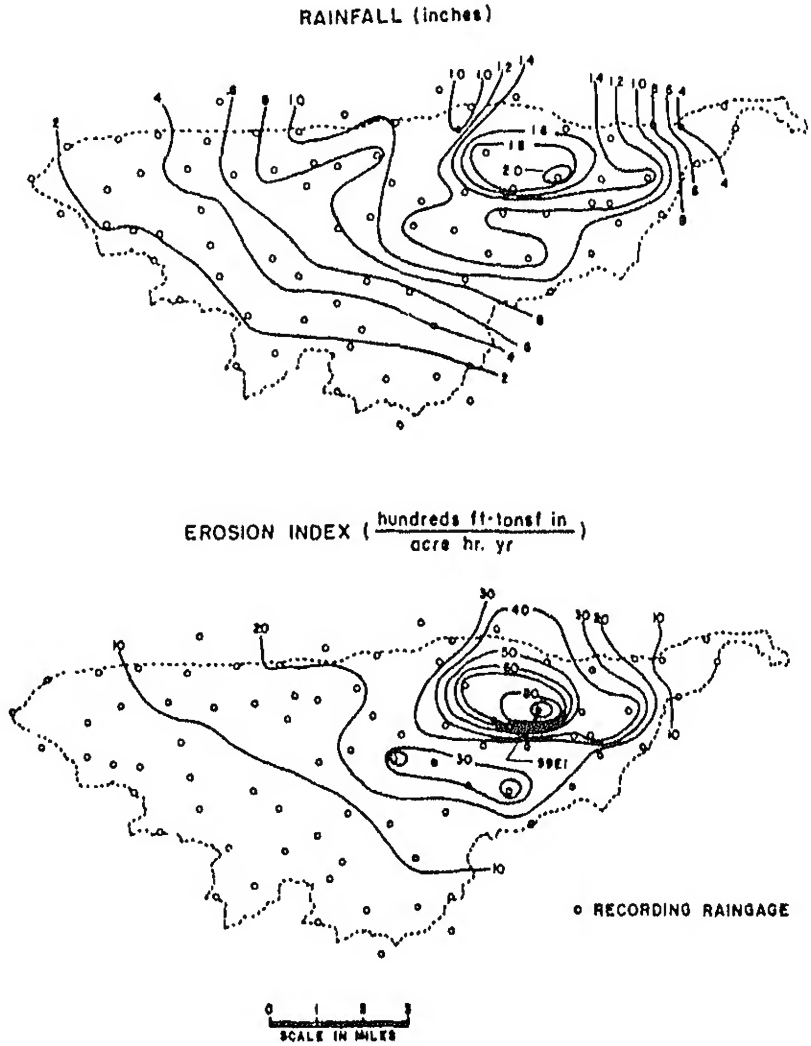

Figure 7.--Isohyetal and isoerodent maps for the July 22, 1964 storm on the Walnut Gulch experimental watershed.

the four watersheds are listed in Table 3. Included in this table are estimated 2 yr EI values using various prediction equations and NOAA Atlas II (Miller et al. 1973) estimates of 2-yr 6-hr rainfall. Figure 11 shows, graphically, the predicted EI of the three equations given the 2-yr 6-hr rainfall.

Table 3.—Actual and predicted average annual EI values using NOAA Atlas II rainfall values and three EI prediction equations.

Location	NOAA 2-yr-6-hr Rainfall (in)	Actual 2-yr EI*	Predicted EI 1/	Predicted EI 2/	Predicted EI 3/
WG					
(63.002)	1.4	54	57	57	47
(63.022)	1.5	58	66	66	53
(63.042)	1.5	56	66	66	53
(63.060)	1.6	64	76	76	58
Safford					
(45.002)	1.2	30	40	41	37
(45.005)	1.3	38	48	48	42
(45.009)	1.3	39	48	48	42
(45.014)	1.4	48	57	57	47
AC					
(64.026)	1.8	68	98	98	71
(64.037)	1.8	70	98	98	71
(64.067)	1.9	76	111	110	77
(64.078)	1.8	68	98	98	71
Albq.					
(47.005)	1.0	25	27	27	27

*EI = $\frac{\text{hundreds ft. tonsf in}}{\text{acre hr yr}}$ from 50% probability from Figure 2 and similar figures.

1/ $EI = 27(P_6)^{2.2}$ P_6 = 2 yr-6 hr rainfall in inches (Ateshian 1974).

2/ $EI = 27.38(P_6)^{2.17}$ (Wischmeier 1974).

3/ $EI = 27.23(P_6)^{1.62}$ from log-log fit of 2-yr 6-hr rainfall and actual 2-yr EI.

The predicted EI values of the first two equations are in considerable error. However, the predicted EI values, using the regionally developed equation, are very close to the actual EI values. The third equation ($EI = 27.23 (P_6)^{1.62}$) was developed using NOAA Atlas II 2-yr 6-hr rainfall values and actual EI values for four widely-spaced raingages on each of the WG, AC, and Safford watersheds and one recording raingage on the Albuquerque watershed. This regionally developed equation is essentially an equation that represents a thunderstorm-dominated rainfall input and, perhaps, could be extended to other areas where thunderstorms dominate the rainfall input.

SUMMARY

Estimating the rainfall erosivity factor for rangelands of the southwestern United States is very difficult because of the thunderstorm dominated hydrology. The EI values vary tremendously, both in time and space, and, on an annual basis, can be dominated by just one storm. Rainfall records from a single recording raingage can be used to estimate the EI only for the area within 0.3 mi radius of that point. Because EI computation is based on maximum 30-min rainfall intensity, most of the EI units are derived from the relatively short, high-intensity portion of the thunderstorm. Thus, in thunderstorm dominated rainfall areas such as Arizona and New Mexico, recording raingages with depths

for short time intervals are needed to compute storm EI. An EI predicting equation that is based on widely available precipitation frequencies was developed for the thunderstorm-dominated regions of Arizona and New Mexico. This equation might also be used in other regions where thunderstorm rainfall dominates the hydrologic and erosion processes.

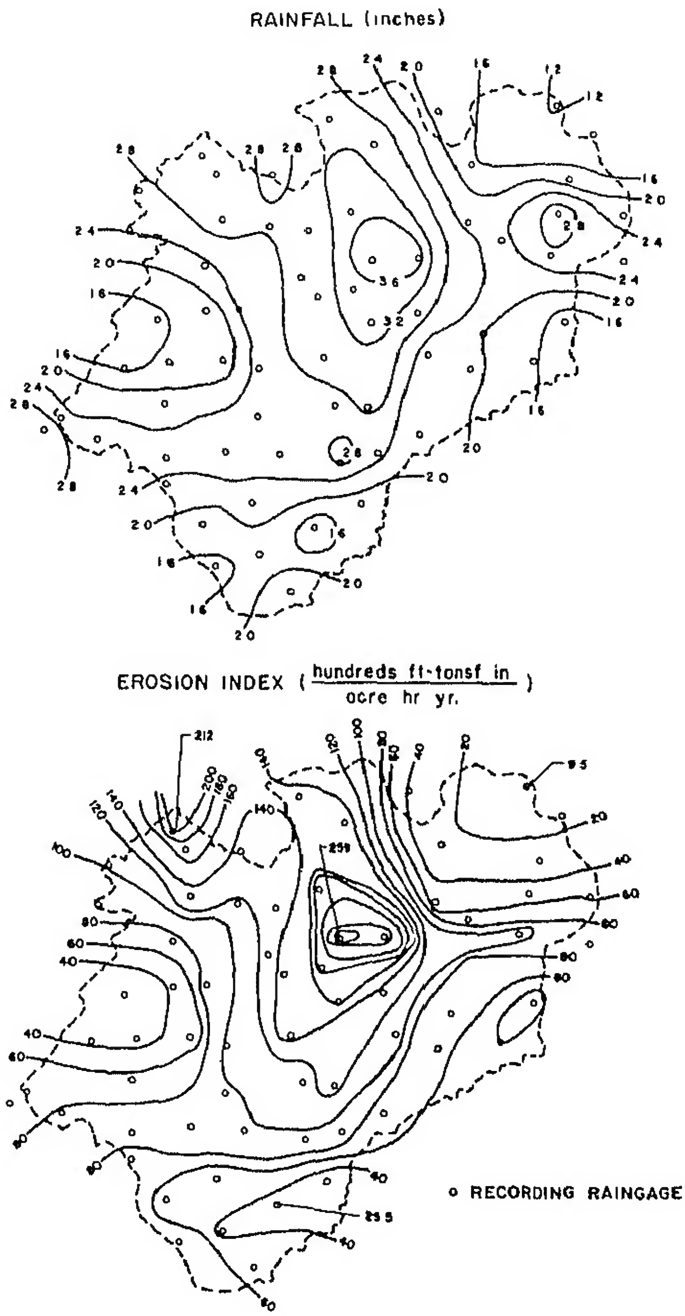

Figure 8.--Isohyetal and isoerodent maps for the July 16, 1966 storm on the Alamogordo Creek experimental watershed.

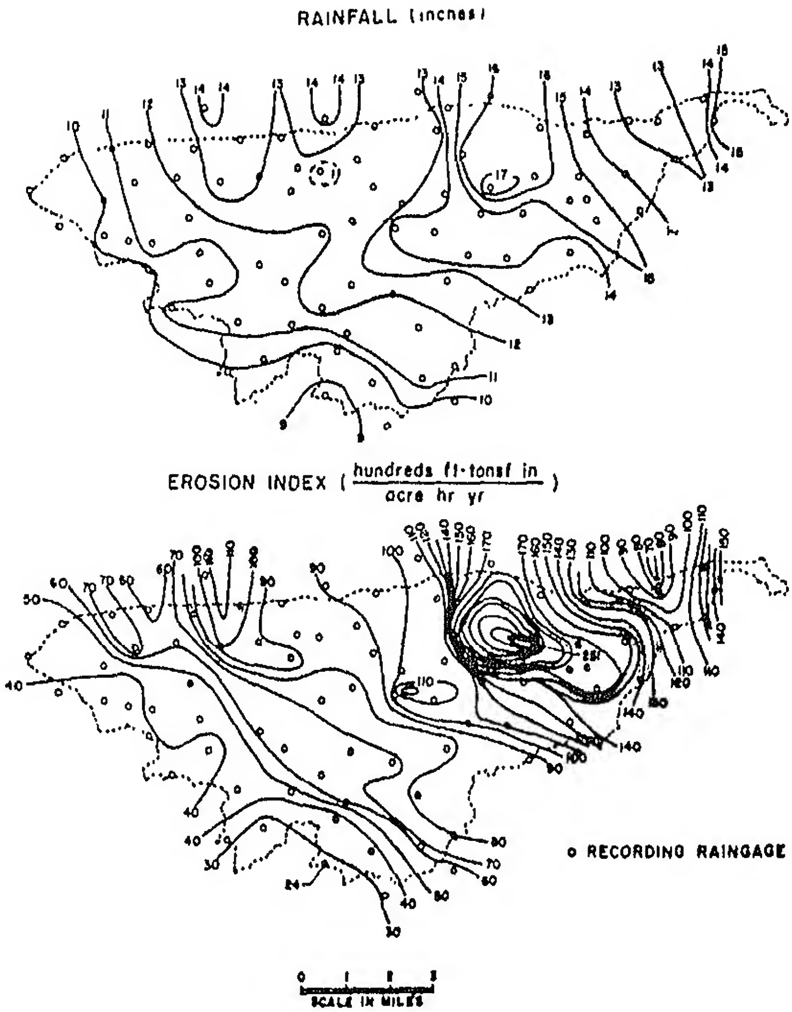

Figure 9.--Isohyetal and isoerodent maps for the 1964 annual totals on the Walnut Gulch experimental watershed.

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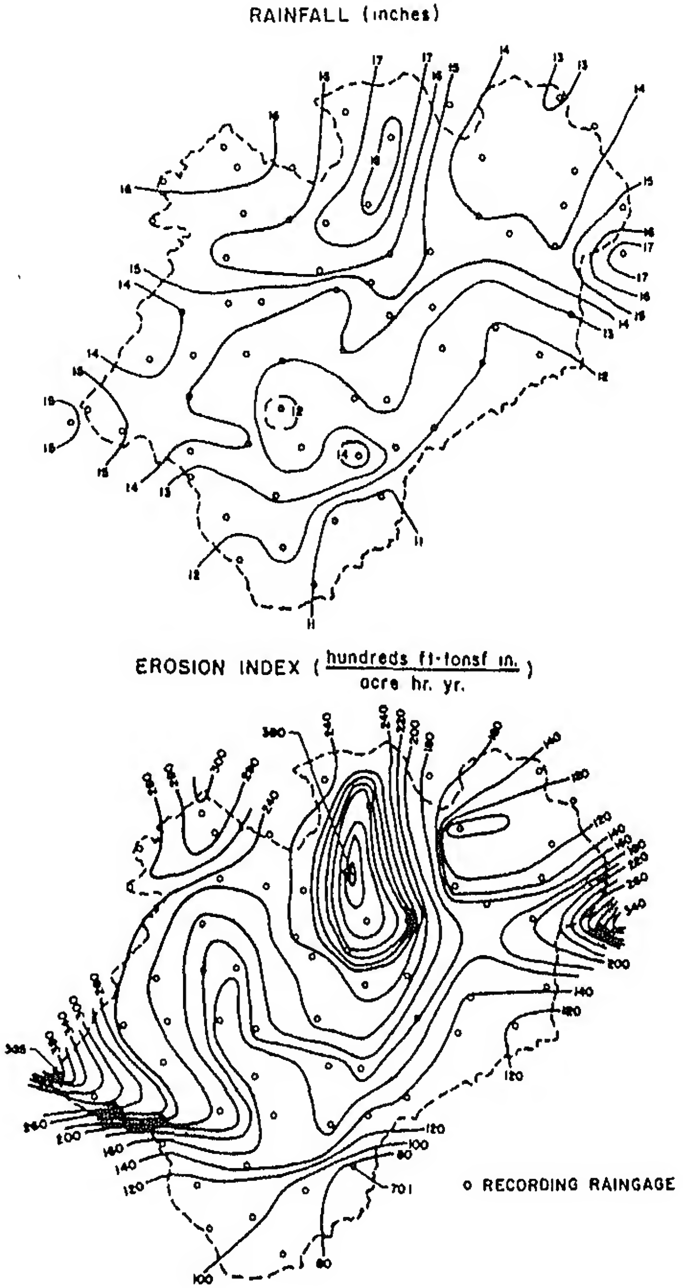

Figure 10.--Isohyetal and isoerodent maps for the 1966 annual totals on the Alamogordo Creek experimental watershed.

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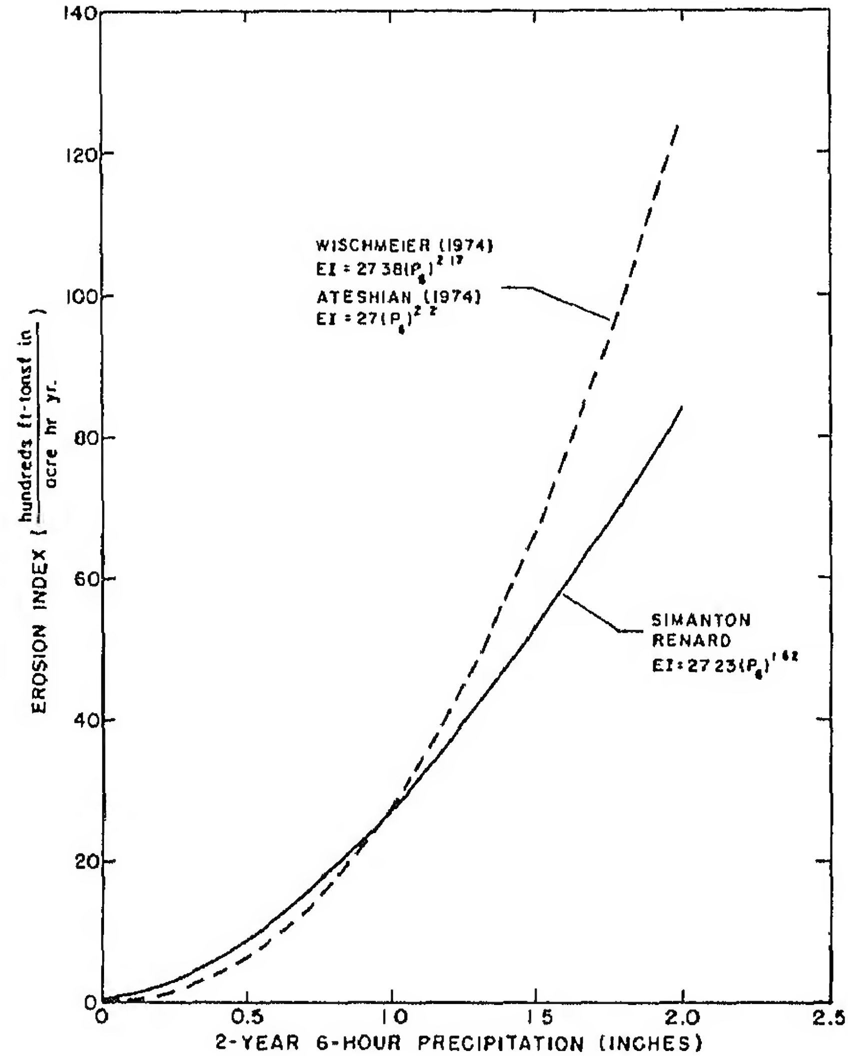

Figure 11.--Erosion index prediction from three equations using the 2-yr 6-hr rainfall.

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SPECIAL PROBLEMS OF THE USLE: SOIL ERODIBILITY (K)

John M. Laflen[1/]

INTRODUCTION

The erodibility of a soil is a quantitative measure of its susceptibility to erosion. According to the recent CREAMS document (Knisel, 1980), the quality of the estimate for a soil erodibility value (K) is "good, based on extensive plot data." Wischmeier and Smith (1978) define K as the rate of soil loss per erosion index unit (R) as measured on a "unit" plot. A unit plot is 72.6 feet long, has a slope of 9 percent, and is maintained in continuous fallow, tilled up-and-down slope. Continuous fallow is land that has been tilled and kept free of vegetation for more than two years. During the period in which K values are determined, the plot is plowed and tilled to a conventional corn seedbed condition each spring and is tilled as needed to prevent vegetative growth and severe surface crusting (Wischmeier and Smith, 1978). Units for K most commonly used have been the ratio of soil loss in tons/acre to EI/100 in ft x t/acre x in/hr. These units will be used in this paper.

Soil erodibility had been discussed and quantified for some period before the Universal Soil Loss Equation (USLE) was developed. It was not until the rainfall factor (R) (Wischmeier and Smith, 1958) was isolated that the erodibility of soils in different climatic regions could be compared. Originally, we accepted the concept that the erodibility of a soil was independent of other factors involved in the erosion process. Present knowledge about the erosion processes of detachment and transport indicates that this concept is not entirely valid but, from a prediction standpoint, may serve a functional purpose. As our ability to model soil erosion improves, we will express a soil's erodibility in a more complex but complete fashion.

In this paper, I intend to review the source of our present K-values and how they have been experimentally determined. Then I will examine some independent evaluations of K-values from natural runoff and rainfall simulation studies.

1/John M. Laflen is an Agricultural Engineer with the Science and Education Administration, U.S. Department of Agriculture, Ames, Iowa. This article is a contribution from SEA, USDA and Iowa State University. Journal Paper J-10268 of the Iowa Agriculture and Home Economics Experiment Station, Ames. Project 2450.

Wischmeier and Smith (1965, 1978) published a set of K-values for soils on erosion-research stations (Table 1). For the 23 values given, 22 are from the study by Olson and Wischmeier (1963). The other soil erodibility value (Hagerstown soil) is from a fallow plot, but the data were unpublished.

As shown in Table 1, K-values for 8 soils on fallow plots had periods of record ranging from 3 to 10 years. Interestingly enough, the longest record was for a Shelby soil, and the benchmark K-value is not from the fallow plot but, rather, from a cropped plot. This could be because of unrealistically large K-values or questionable measurements. The average period of record for the fallow plots was slightly less than 7 years. Plot slopes ranged from 5 to 18 percent; none were on a 9-percent slope. In all cases, except for the Cecil soil in South Carolina, plot lengths were 72.6 feet long. K-values were computed for the fallow plots by adjusting soil loss to unit plot values by using the standard length-slope adjustment for the USLE, then forming the ratio of soil loss to the rainfall factor.

The K-values for cropped plots given by Olson and Wischmeier (1963) also are shown in Table 1. These were computed from data collected during the crop-stage periods 1-3 defined by Wischmeier and Smith (1965). The data were adjusted on the basis of C-values for each crop period given by Wischmeier (1960), contouring factors, and length-slope factors. Only data from plots with intertilled crops that had been turnplowed or spaded were used. R-values were computed for each cropping period. For each contoured plot, in order to adjust for additional surface storage due to tilling across slope on a narrow plot, a critical R-value was established that was the average of R-values for yearly minimum storms that caused soil loss and yearly maximum storms that did not cause soil loss. If a storm did not exceed this critical value, the R was not included, and the R for storms with an R greater than the critical value was reduced by the critical value. Once the data were adjusted, K-values were computed as for the fallow plots.

Direct comparisons of K-values from the fallow plots with those from cropped plots were possible on 5 soils. On 3 soils, K-values were quite similar, while, on the other two soils, K-values differed by 0.10 and 0.12.

Wischmeier and Mannering (1969) related soil erodibility to soil properties using data collected from a rainfall simulation study on 55 Corn Belt soils. They compared soil loss values predicted by their multiple-regression equation with those previously established for 11 soils. These comparisons are given in Table 1. Not all soils that had previously established K-values are among the "benchmark" soils.

The rainfall simulation procedures of Wischmeier and Mannering were to apply an initial 60-min rainstorm (storm 1), then, about 24 hr later, to apply two 30-min storms (storms 2 and 3) separated by about 15 minutes, all at an intensity of about 2.5 in/hr. The R-value for each 30 min of rainfall was 25. The storms, when combined appropriately, gave runoff and soil loss data from rain periods having R-values of 25 (storm 2), 50 (storm 1), 75 (storms 1 and 2), and 100 (storms 1, 2, and 3).

Table 1. Published soil erodibility values

				Olson and Wischmeier (1963)									Wischmeier & Mannering (1969)		Wischmeier et al. (1971)	
			From Ag.Hdbk. 537 (1978)	Record period		Fallow plots			Plot years	Cropped plots						
Soil	Type	State	Benchmark K	From	To	Plot slope	Plot length	K	of data	slope	length	K	Previously established K-values	By multiple regression equation K-values	Established K-values	Nomograph K-values
						%	ft			%	ft					
Albia	gl	NJ	.03	—	—	—	—	—	12	16	70.0	.03	—	—	—	—
Austin	c	TX	.29	—	—	—	—	—	23	4	72.6	.29	—	—	.29	.28
Bath	fsil	NY	—[1,2]	1938	1945	19	72.6	.02	31	19	72.6	.02	—	—	—	—
Bath	fsil	NY	.05	1938	1945	19	72.6	.05	—	—	—	—	—	—	—	—
Boswell	fsl	TX	.25	—	—	—	—	—	41	9	72.6	.25	—	—	—	—
Caribou	l	ME	—	—	—	—	—	—	—	—	—	—	.21	.23	.28	.27
Cecil[5]	scl	NC	—	—	—	—	—	—	—	—	—	—	.36	.29	.28	.28
Cecil	sl	SC	.28[1]	1940	1942	7	18.2	.28[3]	24	7–8	18,66	.25	—	—	—	—
Cecil	sl	GA	.23	—	—	—	—	—	55	3	105	.23	—	—	—	—
Cecil	cl	GA	.26	—	—	—	—	—	43	11	35	.26	—	—	—	—
Cecil	scl	GA	.36	—	—	—	—	—	130	7	70	.36	—	—	—	—
Dunkirk	sil	NY	.69[1]	1939	1946	5	72.6	.69	—	—	—	—	—	—	—	—
Fayette	sil	WIS	.38[1]	1933	1938	16	72.6	.38	48	16	72.6	.37	.38	.38	.38	.42
Freehold	ls	NJ	.08	—	—	—	—	—	85	3–4	70	.08	—	—	—	—
Hagerstown[4]	sicl	PA	.31[1]	—	—	—	—	—	—	—	—	—	—	—	—	—
Honeoye	sil	NY	.28[1]	1939	1941	18	72.6	.28	33	4–19	72.6	.18	—	—	—	—
Houston	c	TX	—	—	—	—	—	—	—	—	—	—	.29	.24	—	—
Ida	sil	IA	.33	—	—	—	—	—	17	14	72.6	.33	—	—	—	—
Keene	sil	OH	.48	—	—	—	—	—	34	8–12	72.6	.48	.48	.46	.48	.46
Lexington[6]	sicl	NS	—	—	—	—	—	—	—	—	—	—	.37	.40	.45	.45
Lodi	l	VA	.39	—	—	—	—	—	80	5–25	58.1	.39	—	—	—	—
Loring	sil	MS	—	—	—	—	—	—	—	—	—	—	—	—	.51	.49
Mansic	cl	KS	.32	—	—	—	—	—	17	5	72.6	.32	—	—	.32	.33
Marshall	sicl	IA	.33	—	—	—	—	—	57	9	72.6	.33	.33	.33	.33	.32
Mexico	sil	MO	.28	—	—	—	—	—	88	3	90	.28	.28	.31	.32	.33
Ontario	l	NY	.27[1]	1939	1946	8	72.6	.27	—	—	—	—	—	—	—	—
Shelby	l	MO	.41	1931	1940	8	72.6	.53	63	8	72.6, 145	.41	.41	.39	.41	.39
Tifton	cls	GA	.10	—	—	—	—	—	65	3	83	.10	.10	.07	.10	.09
Zaneis	fsl	OK	.22	—	—	—	—	—	53	8	72.6	.22	.22	.25	.22	.26

[1] *Evaluated from continuous fallow*

[2] Stones > 2 inches removed

[3] Average of two plots

[4] Unpublished data [72.6 ft long, 13.4% slope, 1935–42 fallow plot data]

[5] *Wischmeier and Mannering* refer to a Cecil scl at Statesville, NC, while Wischmeier et al. refer to a Cecil sl at Statesville, NC

[6] Wischmeier and Mannering refer to a Lexington sicl while Wischmeier et al. refer to a Lexington sil

Plots were 13 ft wide by 35 ft long. Plots, for the most part, had been in rowcrop the three years preceding the tests. Vegetation was clipped close to the surface in the spring and removed before spring plowing and disking. Plots received two additional diskings in late June, and then, two more just before the tests. There were two replicates.

Regression equations were derived that accounted for more than 95 percent of the variance in soil loss from the 110 plots (55 soils, 2 plots each) for each storm size. It is not clear what variables were used in these regression equations. Once derived, the equations were solved for soil loss for unit plot conditions by using expected average values of time-dependent variables for each plot. This then was the adjustment of measured soil loss values to a unit fallow plot value, for each storm.

With the adjusted data, there were four points for a soil loss/R linear relationship. The slope of this linear relationship was the K-value for that soil. Wischmeier and Mannering (1969) then used the derived K-values to relate K to a number of soil properties. The values predicted by the multiple-regression equation afe shown in Table 1.

Wischmeier et al. (1971) presented a soil erodibility nomograph. Data for the nomograph, except for 4 soils, while not explicitly stated, come from the study by Wischmeier and Mannering (1969). The soil loss data from the study by Wischmeier and Mannering (1969) were adjusted to unit plot conditions by generally accepted relationships (I take this to mean those in Agric. Handb. 282, Wischmeier and Smith, 1965). To place observed K's more nearly on an annual basis, average soil losses/EI were computed for a series of

13--storm 1 (one-hr storm),
4--storm 2 (30-min storm), and
3--storm 2 + storm 3 (two 30-min storms).

The justification for this procedure was that K, under natural conditions, is ı average value for annual rainfall patterns that includes an appreciable range storm sizes and antecedent moisture conditions. Barnett et al. (1965) also ed a storm weighting procedure to approximate average annual natural storm esults, but it was different than that of Wischmeier et al. (1971). Most reearchers have tried to weight storms so that the annual natural storms for heir conditions are represented by the weighting procedure.

Independent Evaluations of K

There are only a few instances in which K-values, independently of those eported by Olson and Wischmeier (1963), have been determined for fallow plots y using natural rainfall. The results of one such independent evaluation, for our different soils in the western Corn Belt, are shown in Table 2. In able 3 are shown K-values from these soils computed several different ways.

As shown in Table 2, annual soil erodibility values vary widely. For two f the four locations, standard deviations are about equal to the mean. nfidence intervals of the mean soil erodibility values are quite large for ese two soils. For the other two soils, the confidence intervals are much

Table 2. Soil erodibility values for several plots and years for several soils in the western Corn Belt

	Ida			Grundy			Poinset			Barnes			
Plot No.	3	4		11	20		5	12		5	10	13	
Year	K	K	R[3/]	K	K	R	K	K	R	K	K	K	R
1961	.23	.21	245										
1962	.39	.39	206							.43	.40	.48	312
1963	.27	.30	280	.18	.16	215	.80	.93	135	.03	.03	.03	54
1964	.17	.24	239	.32	.35	382	.10	.14	110	.47	.38	.43	139
1965	.24	.26	208	.19	.24	223	.10	.13	40	.15	.18	.14	78
1966	.02	.01	72	.21	.32	219	.13	.20	52	.10	.13	.03	64
1967	.08	.15	151	.31	.39	149	.28	.20	114	.03	.05	.08	43
1968	.19	.20	202	.37	.37	244	.17	.12	54	.05	.04	.04	48
1969	.29	.29	187	.41	.36	139	.20	.23	140	.10	.06	.04	64
1970	.11	.12	88				.10	.12	53	.31	.29	.20	35
1971							.05	.05	112	.23	.12	.18	76
Mean	.20	.22	188	.28	.31	224	.21	.24	90	.19	.17	.17	91
S[1/]	.11	.11	67	.09	.08	80	.23	.27	40	.16	.14	.17	83
Weighted mean	.22	.24		.28	.31		.26	.28		.28	.25	.28	
a[2/]	-.012	-.009		.307	.321		-.043	-.045		.065	.056	.014	
b	.0011	.0012		-.0001	-.00004		.0029	.0031		.0014	.0012	.0017	
r^2	.46	.57		.008	.0012		.24	.22		.48	.52	.68	
95% Confidence interval of K, based on annual K-values													
From	.12	.14		.20	.24		.03	.03		.08	.07	.05	
To	.28	.29		.36	.38		.39	.45		.30	.27	.29	

1/Standard deviation.
2/Results of regression of K = a + bR for individual plots.
3/Rainfall factor

smaller, but still appreciable. Apparently, the record period should be quite long for accurate estimates of a soil's erodibility, at least in the western Corn Belt.

The hypothesis that the soil erodibility value is independent of R was evaluated by using linear regressions of soil erodibility values on R. These data are shown in Table 2. The hypothesis that soil erodibility values are independent of R was rejected for the Ida and Barnes soil; in both cases, there was a significant positive correlation of K with R. There was no significant correlation for the Grundy or Poinset soils.

The year-to-year variability in R- and K-values is significant as one moves to areas having lower rainfall factors. For example, the ratio of the standard deviation to the mean exceeds 1 for K for the Poinset soil at Madison, South Dakota; it exceeds 0.8 for the Barnes soil at Morris, Minnesota, averages about 0.5 for the Ida soil at Castana, Iowa, and is about 0.3 for the Grundy soil at Beaconsfield, Iowa. This would indicate that longer periods of record are required as the climate becomes more arid.

The data set for the Barnes soil indicate some of the problems encountered in determining K-values from a short period of record. If only the data from 1965-71 are considered, the K-value for that soil would be estimated to be 0.12. If the 1964-71 period is used, K would be estimated to be 0.20, while K is estimated to be 0.27 based on the 1962-1971 period [Note that we do not have all R for the location, only for those storms causing soil loss; hence, the K-values are slightly lower than those in Table 2. Based on data from Mutchler et al. (1976), the K-value for the 1962-71 period would be 0.25]. Obviously, if the period of record had begun in 1965, we would have had a grossly different estimate of soil erodibility. The R-value for 1962 was more than 30 percent greater than that expected once in 20 years and weighted extremely heavily the soil loss on the Barnes soil.

Table 3 shows the results of computing K-values each of several ways for the four soils. These are compared with estimated K-values derived through the use of the published nomograph (Wischmeier et al., 1971) and a soils analysis. The linear-regression method described by Wischmeier (1972) was used for the linear-regression estimate. Wischmeier (1972) defined K as the average increase in soil loss for each additional unit of R for a unit plot; this is the slope of the linear regression line relating storm soil loss (adjusted to unit plot conditions) to storm R.

As shown in Table 3, K-values for the Grundy and Poinset soil computed by any of the methods is within 0.05 of the value computed by the nomograph. Differences are more pronounced for the Ida and Barnes soils.

Young and Mutchler (1977) used a rainfall simulator on 13.3 x 35 ft plots at 2.5 in/hr to determine K-values for 13 soils in Minnesota. Evidently, even though their procedure was to use two 1-hr periods of rainfall about 24 hours apart, which was somewhat different from that used by Wischmeier and Mannering (1969), they combined their storm values similarly to those of Wischmeier et al. (1971). As shown in Table 4, the nomograph values that I computed using their soils data averaged about 50 percent of the values measured in their study. Note that I assumed all soils were fine granular of moderate permeability.

Table 3. Soil erodibility values based on the slope of a linear regression line, long term average, and the soil erodibility nomograph

	Soil erodibility values			
	K_N	K_L	K_{WA}	K_A
Ida	.43	.27	.23	.21
Grundy	.26	.27	.30	.30
Poinset1/	.25	.30	.27	.23
Barnes1/	.17	.38	.27	.17

K_N - From soil erodibility nomograph
K_L - From linear regression of storm soil loss on storm R
K_{WA} - Total soil loss over period divided by total R
K_A - Average of annual soil erodibility values

1/K values based only on storm having soil loss on fallow plots. If all storms were included, K_{WA} and K_A values would be lower, K_L values could be different.

Table 4. Results of Young and Mutchler (1977) for a rainfall simulation study on Minnesota soils

	Silt plus very fine sand	Sand > .10mm	Organic matter	K-values		
				Currently used	Nomograph1/	Study result
	%	%	%	K	K	K
Barnes	39.4	42.1	5.86	.28	.17	.27
Hamerly	44.6	29.6	6.18	.28	.17	.27
Waukon	33.7	49.97	3.49	.24	.15	.14
Rockwood	36.8	48.00	4.13	.24	.16	.33
Nebish	28.9	61.28	2.20	.32	.16	.25
Sioux	23.2	62.40	2.55	.24	.11	.35
Flak	46.2	45.86	1.36	.24	.31	.32
Sverdrup	11.2	80.74	1.73	.20	.06	.11
Kranzburg	49.7	13.80	3.42	.32	.18	.33
Rothsay	39.8	31.10	3.53	.32	.15	.41
Forman	38.8	27.3	3.76	.28	.13	.23
Clarion	27.9	41.50	4.28	.28	.09	.35
Storden	30.4	46.00	3.60	.28	.12	.36
		Average		.27	.15	.29

1/Nomograph values computed by assuming each soil is fine granular with moderate permeability.

Also, because the nomograph of Wischmeier et al. (1971) has a maximum of 4 percent for organic matter, if organic matter exceeded 4 percent (as it did for four of the soils), the value used in the nomograph for that soil's organic matter was 4 percent.

Young and Mutchler (1977) indicated that the differences between measured and nomograph K-values (adjusted based on judgment of soil conservation service personnel) was due to differences in the clay fraction (Montmorillonite was dominant) and the degree of aggregation between the soils used in the study by Wischmeier and Mannering (1969) and their study. They indicated that the good agreement of their K-value with the K-value from the fallow plot (Table 3, Barnes) gave credence to the reliability of the methods used. However, as shown in Table 2, the data for the fallow plots were weighted heavily by one year's record.

In 1979, Laflen and Piest (unpublished data) conducted a rainfall simulation study to determine K-values for two soils on the Treynor watersheds near Council Bluffs, Iowa (Table 5). K-values are adjusted for slope and length but not for prior cropping. For each soil, antecedent conditions were quite similar. Plot preparation was similar to that described by Wischmeier and Mannering (1969).

Table 5. Results of soil erodibility studies at Treynor, 1979 (unpublished data by Laflen and Piest)

Plot	Soil type	Slope	K1/	K2/
1	Ida	13.2	.35	.33
2	Ida	12.6	.32	.31
3	Ida	10.6	.51	.48
4	Ida	10.0	.46	.46
5	Monona	6.1	.63	.63
6	Monona	5.9	.68	.66
7	Monona	5.6	.60	.62
8	Monona	6.3	.60	.59

1/Computed based on sequence of storms given by Wischmeier et al., 1971. Data adjusted for slope and length.

2/Computed based on slope of regression line similar to the method of Wischmeier and Mannering, 1969. Data adjusted for slope and length.

Computed K-values for each soil were quite similar regardless of the calculation procedure. For the Monona soils, slopes and K-values were similar for all plots. For the Ida soil, there was a considerable difference in K-values, evidently because of the major slope difference among the plots. The slope adjustment factor could be quite important in adjusting simulated or natural rainfall data, and plots on identical soils at different slopes could have different K-values because of the adjustment.

SUMMARY AND CONCLUSIONS

Most of the questions raised may have confused, rather than clarified, the state of knowledge concerning soil erodibility values. On the basis of the data presented, it is difficult to agree that the quality of the estimate for a soil erodibility value is "good." However, relative to other variables in the USLE, the quality of the estimate might be "good."

The data shown do reveal that results from natural or simulated rainfall studies must be analyzed very carefully. There is little here, except that, to reveal much else in terms of guidance. Most researchers have tried in some way to compute K-values based on the kind, number, and frequencey of storms expected.

It is distressing to observe that the data for established K-values came from plots that were not unit plots (all data required adjustment) and, for benchmark values from fallow plots, were the result of very short periods of record. For the cropped plots used to derive benchmark K-values, the number of years over which the records were collected were not given.

The equation derived by Wischmeier and Mannering (1969) and the nomograph by Wischmeier et al. (1971) were used to compute K-values for several benchmark soils. In both cases, there was excellent agreement. Yet, when I used Young and Mutchler's (1975) data, I found very poor agreement, evidently because of the clay type. This clearly indicates that not all differences in K can yet be accounted for.

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EFFECTS OF SLOPE LENGTH AND STEEPNESS ON SOIL EROSION FROM RANGELANDS[1/]

D. K. McCool, Agricultural Engineer

INTRODUCTION

Determination of how slope length and steepness influence soil erosion from rangelands has long been a source of frustration and concern for range scientists and hydrologists in both research and management agencies. Data on the effect of slope length and steepness from naturally occurring precipitation events on rangeland are virtually nonexistent. Rangeland runoff and soil loss plots must frequently be located in remote areas, making them costly to install and maintain, and are generally subject to infrequent natural events. After-the-event survey-type studies will not provide data to establish firm relationships. Rainfall simulator studies on rangelands have generally been conducted only on small plots where the conditions studied simulate only the upper portion of the slope. Results from such simulator studies have been quite variable. The lack of well-substantiated relationships has caused rangeland management personnel to lack confidence in the entire soil erosion prediction technology.

The purpose of this study was to examine and evaluate the existing relationships, theory, and data that relate soil erosion to slope length and steepness. Tentative working relationships for the influence of slope length and steepness on erosion from rangelands are suggested.

PAST AND CURRENT RESEARCH

Renner (1936) published results of a previous investigation of conditions influencing erosion on rangelands of the Boise River watershed. Data were collected by field survey of 1,196 areas or sampling points within the 1,700,000 acre watershed. Information was collected on several factors including slope steepness, aspect, soil, plant type, vegetation density, and accessibility to livestock. Effect of slope steepness was found to increase to a maximum at about 35 percent (19.3°) slope.[2/] However, the decrease beyond 35 percent resulted largely from inaccessibility to domestic grazing animals. When grazing influence was removed, erosion increased with slope steepness above 35 percent. A few sites with slope steepness over 86 percent were measured, but slope steepness of 98.8 percent of the sites sampled was below 65 percent (33.0°). Slope length was not considered in the study.

1/Land Management and Water Conservation Research Unit, USDA-ARS, Washington State University, Pullman, WA 99164. In cooperation with the College of Agriculture Research Center, Washington State University.

2/Throughout this manuscript percent slope = 100 tan θ, where θ = slope steepness in degrees.

Horton (1945) used the Du Boys and Manning equations to develop for overland flow a relationship between shearing force on the soil and slope length and steepness. The Du Boys equation was written in the form:

$$F_1 = w_1 \frac{\delta_x}{12} \sin \theta \tag{1}$$

where[3/] F_1 = force exerted parallel with soil surface per unit of slope length and width,
w_1 = weight per cubic foot of water,
δ_x = depth of overland flow at distance x from divide or watershed boundary, in inches, and
θ = slope steepness, degrees.

The Manning equation was written in the form:

$$q_s\ x = (686.8)\ \frac{1.486}{n}\ \delta_x^{5/3}\ s^{1/2} \tag{2}$$

where q_s = runoff intensity in inches per hour,
x = distance from divide or watershed line, along or on slope, in feet,
n = Manning roughness factor, and
s = slope steepness, defined by Horton as $\tan \theta$.

Equations (1) and (2) can be combined to yield:

$$F_1 = \frac{w_1}{12} \left(\frac{q_s\ n\ x}{1020}\right)^{3/5} \frac{\sin \theta}{(\tan \theta)^{0.3}} \ . \tag{3}$$

This relationship reaches a maximum value at about 57 percent (29.7°) slope (Horton's graphic data were incorrect) and decreases to zero at 90° slope. Renner's data were presented to support the relationship but the interpretation is questionable. Horton used $\tan \theta$ for slope steepness in Manning's equation. If Horton had used $\sin \theta$ for slope in the Manning equation as he did in the Du Boys formula, equation (3) would have been:

[3/] In this manuscript symbols of the cited publication will generally be used. Since different authors have used the same symbol with different definitions, all symbols in equations will be defined immediately following the equation. If the meaning of a symbol is the same in consecutive equations, the symbol will be redefined only if necessary to assist the reader.

$$F_1 = \frac{w_1}{12}\left(\frac{q_s\ n\ x}{1020}\right)^{3/5} (\sin\theta)^{0.7}. \tag{4}$$

This relationship reaches a maximum value at a 90° slope.

Horton did not discuss length of slope in his study, but if soil loss per unit area is assumed to vary directly with F_1, as he did, then soil loss per unit area varies with x to the 3/5 power.

Packer (1951) reported a series of rainfall simulator tests in which a modified Type F infiltrometer was used to apply 1.80 in of artificial rainfall on 6-ft square plots at the rate of 3.60 in/hr. The plots were on an ungrazed portion of the Boise River watershed. The purpose of the study was to test the influence of certain variables on overland flow and erosion. Fourteen perennial bluebunch wheatgrass (Agropyron inerme) and sixteen cheatgrass (Bromus tectorum) plots were tested. Slope steepness ranged from 33 to 66 percent. Several findings were noted, but the main one of interest to this review is that slope steepness had no significant effect on runoff or erosion. The shortness of the plots was mentioned as a possible reason, because there was no opportunity for flow to concentrate and rills to develop.

Findings similar to Packer's were reported by Megahan (personal communication) for forest slopes in Idaho. Megahan found no correlation between slope steepness and erosion on runoff plots 10.0 ft wide by 43.6 ft long on slopes of 39 to 72 percent steepness.

The effect of slope length and steepness on soil erosion from cropland has been evaluated by several researchers. Zingg (1940) summarized data collected under artificial and natural rainfall conditions from several research plots in the Great Plains, Midwest, and East, and developed the relationship:

$$A \propto \lambda^{0.6}\ s^{1.4} \tag{5}$$

where A = average soil loss per unit area,
λ = horizontal length of slope, and
s = slope steepness, percent.

Musgrave (1947), summarizing the recommendations of a group of workers, published the relationship:

$$A \propto \lambda^{0.35}\ s^{1.35}. \tag{6}$$

Smith and Whitt (1947) published results for a claypan soil [Putnam (fine, montmorillonitic, mesic Mollic Albaqualfs)]. They suggested a general equation for effect on erosion of slope steepness:

$$A = a + b\ s^n \tag{7}$$

where a,b,n = constants influenced by rainfall intensity, soil, and cover.

They used rainfall simulator data of Neal (1938) to produce the relationship:

$$R = 0.10 + 0.21\ s^{4/3} \qquad (8)$$

where R = soil loss ratio or multiplier.

The product of R from equation (8) and measured soil loss on the McCredie, Missouri experimental farm plots (3 percent slope) become estimated soil loss on a given rotation on a 90-ft plot of the selected slope steepness. Plot data from Shelby soil (fine-loamy, mixed, mesic Typic Argiudulls) at the Bethany, Missouri Experiment Station (Smith et al., 1945), and publications of Zingg (1940) and Musgrave (1947) were cited in suggesting a slope length exponent of 0.6 for the claypan soil which was considered to allow greater runoff and to be more easily detached and transported than the Shelby soil.

By 1957, cropland soil loss data from fairly long periods were available from several locations. Specifically, seventeen years of data were available from four slope groups of from 3 to 18 percent on a Fayette soil (fine-silty, mixed, mesic Typic Hapludalfs) at the experiment station at LaCrosse, Wisconsin, and seventeen years of data were available from Blacksburg, Virginia, on five slope groups of from 5 to 25 percent. Smith and Wischmeier (1957) used a parabolic equation to fit the Wisconsin data. Data from Zingg's rainfall simulator tests (1940) and studies at Dixon Springs, Illinois, and Zanesville, Ohio, fit the pattern of the Wisconsin relationship. Thus, data from these four studies were combined to obtain, by least squares fit, the equation:

$$A \propto 0.43 + 0.30\ s + 0.043\ s^2. \qquad (9)$$

The Virginia data showed a nearly linear relationship:

$$A \propto 0.24 + 0.55\ s - 0.004\ s^2 \qquad (10)$$

and were not included in developing equation (9).

Smith and Wischmeier (1957) reported length of slope data from 136 location years at ten locations under corn or cotton. The data were fit to an equation of the form:

$$A \propto \lambda^m \qquad (11)$$

where A = average soil loss per unit area,
λ = slope length, and
m = fitted exponential constant.

Average values of the length exponent for the different locations ranged from 0 to 0.9, with a location-weighted average of 0.46. The authors were unable to discern an adequate explanation for the variation, although they stated "Magnitude of the length exponent appears to be related both to soil and cover, but more positively to runoff."

In their significant and widely used publication of 1965, in which the Universal Soil Loss Equation (USLE) was presented, Wischmeier and Smith referred to their previous publication (1957) when presenting the following slope length and steepness relationships:

$$A \propto (\lambda)^{0.5} (0.43 + 0.30s + 0.043s^2) \tag{12}$$

where A = average soil loss per unit area,
λ = slope length, and
s = slope steepness, percent.

Later, after significant use of the USLE was being made on steeper slopes on rangeland, forest land, mine spoil areas, and construction sites, Wischmeier and Smith (1978) modified their relationships so that the slope steepness influence was not so large for steep slopes.

$$LS = (\lambda/72.6)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065) \tag{13}$$

where LS = slope length and steepness factor relative to a 72.6 ft slope length of uniform 9 percent ($\theta = 5.1^o$) slope,
λ = slope length, feet,
θ = slope steepness, degrees, and
m = 0.5 if percent slope is 5 or more, 0.4 on slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent, and 0.2 on uniform slopes of less than 1 percent.

Meyer and Monke (1965) examined existing erosion and sediment transport equations and compared values of exponents on slope length and steepness. Their literature study was preliminary to conducting a series of laboratory experiments with artificial rainfall on a cohesionless bed consisting of uniform-sized particles. Their flume was 9.8 ft (3.0 m) long, 2 ft (0.6 m) wide, and 0.8 in (2 cm) deep with an impermeable bed. Flow rates were equivalent of 1.5 in/hr with water added at the upper end to give equivalent lengths of 10, 40, 70, and 100 ft. Various slope steepnesses to 16 percent slope were used. Sediment was added at the upper end of the flume so that there was no net loss of sediment from the bed. Thus the study was primarily an evaluation of the sediment transport capacity of overland flow.

In their data analysis, they introduced the concepts of critical lengths and steepnesses:

$$e_r = C_s (s - s_c)^n \tag{14}$$

and

$$e_r = C_\lambda (\lambda - \lambda_c)^m \tag{15}$$

where e_r = sediment transport by runoff per unit of width,
C_s = constant,
s = slope steepness, percent,
s_c = critical slope steepness, percent,
n = exponential constant,
C_λ = constant,
λ = slope length,
λ_c = critical slope length, and
m = exponential constant.

Values of m were determined experimentally to be near 1.5. Values of n were mostly in the 2.0 to 2.5 range, much larger than the 1.35 to 1.4 values in use at that time for the influence of slope steepness on erosion (equations 5 and 6). The study primarily addressed the transport phase of the erosion process.

Young and Mutchler (1969) reported results from an artificial rainfall study on Crofton silt loam [fine-silty, mixed (calcareous), mesic Typic Ustorthents] in southeastern South Dakota. They shaped concave, convex, and uniform slopes with local steepness of 5 to 15 percent and average steepness of 9 percent. The plots were 13.5 ft wide by 75 ft long. Artificial rainfall at 2.5 in/hr was applied in four half-hour applications. Fluorescent glass particles were used to determine relative movement. When soil losses from rill measurements taken at intervals along the slope were considered, 88 percent of the variance was accounted for by the relation:

$$E = -15.38 + 0.26\ R + 1.31\ s \tag{16}$$

where E = soil loss, ton/acre,
R = runoff, cubic ft, and
s = slope steepness, percent.

When fitted to a power model:

$$E = 0.0145\ R^{1.24}\ s^{0.74} \tag{17}$$

with a coefficient of determination of 0.87. The authors indicated that raindrop splash was a major contributor to soil detachment and to transport of soil particles to a rill system.

Partheniades (1965) investigated the influence of shear stress, suspended sediment concentration, and bed shear strength on erosion rates. A straight rectangular flume 12 in wide by 15 in deep by 60 ft long with bed material 0.1 ft thick was used with a recirculating water system and water at ocean salinity. Bed material was a special clay commonly called San Francisco bay mud. Water depth was 6 in, and no artificial rainfall was applied. For the test range of bed strengths, erosion rates were independent of the bed shear strength and of the suspended sediment concentration. The erosion rates depended strongly on shear stress, increasing rapidly after a critical value was reached.

Foster and Martin (1969) conducted a laboratory experiment to determine the effect of slope and bulk density on soil loss. The test apparatus was a small channel 5 in wide by 35 in long. Test slopes were 18.5°, 26.5°, and 45°, and dry bulk density values of the "Gallatin No. 1" soil were 80, 85, 90, and 95 lb/ft^3. Four replicates were run. Artificial rainfall was applied with a spray nozzle; no application rates, drop sizes, or drop velocities were given. Foster and Martin found an interaction between slope steepness and bulk density. On the 18.5° slope, erosion decreased with increasing bulk density; on the 26.5° slope, erosion was maximum at bulk densities of 85 to 90 lb/ft^3; and on the 45° slope, erosion increased with increasing bulk density.

Gregory et al. (1977) developed a relationship for soil loss from steep slopes. They used a relationship of Ekern (1950) for splash transport, data from Palmer (1965) to determine a rate of decrease of raindrop-caused strain on individual particles on the soil surface with increase of water depth, and a relationship of Laws and Parsons (1943) to determine a relationship between raindrop size and intensity. The Gregory et al. equation included various corrections for steep slopes; these corrections included calculating rainfall and watershed area on a projected area basis. Inasmuch as rainfall and area are commonly calculated on a projected area basis and do not need correction, these two corrections should be deleted from their equation. If all area, slope length, and rainfall calculations are made on a projected area basis, their equation for the influence of slope steepness on erosion is:

$$S = \frac{0.50\ (\sin\theta)^{1.249} + (\sin\theta)^{2.249}}{0.02899} \tag{18}$$

where S = slope steepness factor relative to 9 percent slope (θ = 5.1°), and

θ = slope steepness, degrees.

In a later development, Gregory and Steichen (1978) considered the effect of bulk density by separating the impact force causing detachment into normal and tangential components relative to the soil surface. They assumed that the tangential component affected the rate of soil erosion through a shearing process and that the normal component affected the hydrostatic pressure in the soil pores. Hence the influence of bulk density was through pore size. The data of Foster and Martin (1969) were used to calibrate the relationships for detachment caused by forces normal to the soil surface. Gregory and Steichen showed that the slope steepness relationship reported by Zingg (1940), equation (5), and the relationships reported by Wischmeier and Smith (1957), equations (9) and (10), could be reproduced by assuming certain specific values of surface bulk density. If the projected area is assumed for all rainfall and area calculations and Gregory and Steichen's component for roughness is deleted, the relationship for slope steepness reduces to:

$$S = \frac{\left[\dfrac{2095\left(1 - \dfrac{BD}{2.65}\right)^{11.9} \cos^2\theta}{0.1 + s} + 0.6 \sin\theta\right]\left[0.5 (\sin\theta)^{1.249} + (\sin\theta)^{2.249}\right]}{317\left(1 - \dfrac{BD}{2.65}\right)^{11.9} + 0.00156} \tag{19}$$

where S = slope steepness factor relative to 9 percent slope ($\theta = 5.1^{\circ}$),
θ = slope steepness, degrees,
BD = surface bulk density, g/cc, and
s = slope steepness, $\tan\theta$.

Foster and Meyer (1972) developed a closed-form erosion equation by using continuity of mass and an equation expressing the interrelationship between detachment by flow and sediment load. They assumed that the ratio of detachment rate to detachment capacity plus the ratio of sediment load to sediment transport capacity equals 1. Detachment capacity and transport capacity were taken as functions of the 3/2 power of the flow's tractive force. Using a relationship between rainfall excess and distance along the land profile, the Chezy uniform flow equation, and the above relationships, they derived a closed-form equation for detachment rate and sediment load along a particular land profile. Equations for slope length and slope steepness exponents were developed. These were quite complex and are not included in this manuscript.

Research reported by Meyer et al. (1975b), indicated that slope steepness has much less effect on soil loss from short interrill areas than would be calculated from the relationships developed from longer plots and reported by Smith and Whitt (1947) and Wischmeier and Smith (1957, 1965, and 1978). Meyer et al. (1975b) reported that considerable erosion occurred even when the soil surface was level, but the increase in erosion with slope steepness over a broad range of steepness was relatively small. Erosion only doubled for a steepness change from 2 to 20 percent, whereas the Wischmeier and Smith (1957, 1965, and 1978) relationship indicates a nearly 20-fold increase.

In 1975, Foster and Meyer (1975) separated sediment load into rill and interrill components using the closed form equation reported previously [Foster and Meyer (1972)]. They mentioned that, generally, the effect of slope steepness on soil loss has been reported as $G \propto s^p$ with the value of p ranging from 0 to 2. They suggested that where runoff rate, runoff duration, and rill density are independent of slope steepness, and where surface roughness is unimportant, a p value of 0 to 1 should be reasonable. Steeper construction slopes, such as highway embankments, were cited as examples where p might vary from 0 to 1.

Meyer et al. (1975a) investigated the effect of flow rate and crop canopy on rill erosion on cropland. They used a rainfall simulator with application rates of 2.5 and 5.0 in/hr and they introduced a clear water inflow at the upper end of 15-ft rills on a 6 percent slope. Tests were conducted with and without canopy, which was simulated by layers of window

screen. Meyer et al. (1975a) proposed an equation for the rate of soil loss from rills:

$$E_T = E_I + D_R (Q-Q_c) \tag{20}$$

where E_T = upland erosion,
E_I = interrill erosion,
D_R = coefficient that depends on susceptibility of a given soil to rill erosion,
Q = rill flow rate, and
Q_c = critical discharge below which erosion is negligible.

In their tests, rill erosion was observed to be a complex combination of headcuts, detachment by shear, and slumping of undercut side slopes. They proposed:

$$E_R = E_S + E_H \tag{21}$$

where E_R = rill erosion,
E_S = rill shear erosion, and
E_H = rill headcut erosion.

They cited earlier analysis (Foster and Meyer, 1975), which indicated that E_S is related linearly to flow rate, and work of Piest et al. (1975) wherein gully headcut erosion was found to vary with flow rate to a power between 1.0 and 1.5. Meyer et al. (1975a) then suggested a relationship that lumps shear and headcut erosion:

$$E_R = B_1 (Q-Q_c)^{B_2} \tag{22}$$

where E_R = rill erosion, and
B_1, B_2 = coefficients.

Their data indicated a value of 1.07 for B_2, but they suggested that a value of 1.0 be used.

On uniform slopes, E_I can be assumed reasonably constant over the entire slope length and independent of rill flow rate. Hence:

$$G_T = W [D_I\lambda + (D_R/2) Q_A (\lambda - \lambda_c)^2] \tag{23}$$

where G_T = total eroded sediment,
W = width of rectangular area,
D_I = sediment delivery rate from the interrill portion,
λ = slope length to location of interest,
D_R = rill erodibility coefficient,

Q_A = runoff rate per unit area, and
λ_c = distance downslope at which $Q = Q_c$.

The first term, $WD_I\lambda$, of equation (23) expresses the contribution to total eroded sediment by interrill erosion; the remainder expresses the rill contribution. This relationship was used to explain wide differences in slope length exponents that have been found by various investigators.

Foster et al. (1977a) developed the relationship:

$$G = \int D_i \, dx + \int D_r \, dx = G_i + G_r \tag{24}$$

where G = sediment load,
D_i = detachment rate by interrill erosion,
D_r = detachment rate by rill erosion,
G_i = sediment load due to interrill erosion, and
G_r = sediment load due to rill erosion.

Data of Meyer et al. (1975b) were cited which indicated that the relationship of interrill detachment to slope steepness was linear for slopes less than 15 percent. Foster et al. proposed an equation as follows:

$$D_i = K_i \, I \, (b \, s + c) \tag{25}$$

where D_i = detachment rate by interrill erosion,
K_i = soil erodibility factor for interrill erosion,
I = measure of combined potential of raindrop impact and interrill flow to detach and transport soil particles to rills,
s = slope steepness, and
b and c = coefficients to be determined by experimentation and analysis.

Foster and coworkers suggested an equation for rill detachment as follows:

$$D_r = a_s(\tau_e - \tau_c)^{\xi} \tag{26}$$

where D_r = detachment rate by rill erosion,
a_s = factor related to soil's susceptibility to rilling,
τ_e = effective shear stress,
τ_c = critical shear stress, and
ξ = exponent.

If critical shear stress is assumed to be negligible, the above equation becomes:

$$D_r = a_s(\tau_e)^{\xi} . \tag{27}$$

Foster et al. (1977a) used data from Partheniades (1965) to establish limits on ξ; for the upper range of shear stress, $D_r \propto \tau_e^{2.0}$; for the lower range of shear stress, $D_r \propto \tau_e^{1.0}$. Foster and coworkers selected a value of 1.5 for ξ. This value was in agreement with data of Meyer et al. (1975a) "for rill erosion where headcutting and undercutting of the rill sidewalls were present along with shear erosion."

Foster et al. (1977a) then used the Du Boys and Darcy-Weisbach equations to develop an equation for effective shear stress:

$$\tau_e = C_\tau \gamma (f/8g)^{1/3} s^{2/3} q^{2/3} \qquad (28)$$

where τ_e = effective shear stress,
C_τ = τ_e/τ_a,
τ_a = average shear stress from $\tau_a = \gamma y s$,
γ = weight density of the runoff,
y = depth of overland flow,
s = slope of energy grade line (assumed equal to land slope),
f = friction factor,
g = acceleration due to gravity, and
q = discharge per unit width.

If σx is substituted for q where σ = excess rainfall rate and x = horizontal distance, then from equations (27) and (28):

$$D_r = a_s C_\tau^{3/2} \gamma^{3/2} (f/8g)^{1/2} s \sigma x. \qquad (29)$$

By making appropriate substitutions and integrating:

$$G_r = K_r (a s^e) \sigma x^2 \qquad (30)$$

where G_r = sediment load from rilling,
K_r = soil factor for rilling, and
a and e = functions of tillage pattern, soil roughness, and other factors that interact with slope steepness to influence rill erosion.

The total erosion equation is then:

$$G = G_i + G_r = K_i I (bs + c) x + K_r (a s^e) \sigma x^2. \qquad (31)$$

In another paper (Foster et al., 1977b), a value for e of 2.0 was assumed, basically because, based on data reported by Wischmeier (1966), slope steepness was assumed to affect runoff amount, rill pattern, and rill cross-sectional shape. Hence:

$$A = K_i\ (b\ s + c)\ I_i\ C_i\ P_i + K_r\ (a\ s^2) F_t\ C_r\ P_r\ (x/\lambda_u) \qquad (32)$$

where A = average soil loss per unit area for slope length x,
I_i = rainfall erosivity,
F_t = runoff erosivity,
K_i and K_r = soil erodibility factors for interrill and rill erosion, respectively,
C_i and C_r = cropping-management factors for interrill and rill erosion, respectively,
P_i and P_r = supporting practice factors for interrill and rill erosion, respectively,
x = distance downslope from origin of overland flow,
s = slope steepness expressed as sine of slope angle,
λ_u = length of the unit plot (72.6 ft), and
a, b, and c = coefficients.

The soil erodibility, cropping-management, and supporting practice factors are modified from those customarily used in the USLE (Wischmeier and Smith, 1965, 1978).

The 1978 slope steepness relationship of Wischmeier and Smith (1978) was tested under artificial rainfall conditions at the Utah State University Water Research Laboratory (UWRL) (National Research Council, 1980). The tube or needle drip-type rainfall device produced 4 mm drops. The long drop fall distance (16 ft maximum) was less than necessary to produce terminal velocity. The plots were 4 ft wide and 19.5 ft long.

The plots were filled with three different soils: (1) a washed sand, (2) Nibley silty clay loam (fine, mixed, mesic, Aquic Arguistolls) from Logan, Utah, (3) Cecil gravelly loam (clayey, kaolinitic thermic, Typic Hapludults) from Watkinsville, Georgia, and (4) the same Nibley soil used for plot (2) except the soil was compacted and not tilled. Plots 1 through 3 were tilled up and down the slope. Slopes of 9, 25, 50, and 84 percent were tested. Rainfall intensities were 2.51, 3.95, and 7.65 in/hr with durations of 30, 15, and 8 or 10 min, respectively.

When the 20-ft-long flume was tilted to the 84 percent slope steepness, there was approximately 2.8 ft between the drop emitters and the upper end of the test section and approximately 15.3 ft between the drop emitters and the downstream end of the test section. This produced a ratio of rainfall energy levels of approximately 1 to 4 between the upper and lower ends of the 19.5-ft test section.

In verifying the Wischmeier and Smith (1978) slope steepness relationship, UWRL apparently calculated rainfall energy on a projected area basis. Erosion, however, was calculated on a slope-area basis. The researchers concluded the Wischmeier and Smith (1978) relationship was valid for slopes of up to 100 percent steepness.

The UWRL researchers also broke the Wischmeier and Smith slope steepness relationship into two curves, one for slope steepness of less than

20 percent, and another for slope steepness from 20 to 100 percent, and by least squares fit of calculated values obtained the linear relationships:

Less than 20 percent slope
$$LS = \left(\frac{\lambda}{72.6}\right)^m 0.174\ s \qquad (33)$$

20 to 100 percent slope
$$LS = \left(\frac{\lambda}{72.6}\right)^m (0.413\ s - 4.78) \qquad (34)$$

where LS = slope length and steepness factor relative to a 72.6 ft slope length of uniform 9 percent (5.1°) slope,
λ = length along slope, ft, and
s = slope steepness, percent.

The coefficient of determination for equation (34) was 0.91. A plotting indicated the nearly linear relationship between slope steepness, s, and the USLE slope steepness factor, S, between 20 and 100 percent slope for the Wischmeier and Smith (1978) relationships.

Trieste and Gifford (1980) published the results of an analysis of rainfall simulator data collected from some 2,805 plots representing a variety of conditions in the western United States and Australia. The purpose of the analysis was to test the relationships of the USLE using a per-storm analysis of rainfall simulator data. The data had been collected using three different types of rainfall simulators: (1) the Rocky Mountain infiltrometer with rainfall at 3.0 in/hr on a 2.5-ft^2 plot, (2) a modular drip-type device with intensities of from 0.2 to 3.3 in/hr on a 9-ft^2 plot, and (3) a modular drip-type device with 3 in/hr intensity and a plot size of 4-ft^2 designed especially for use on steep slopes and bare soils.

The variable that best explained soil loss was the slope steepness factor, S, of the USLE (Wischmeier and Smith, 1978). The slope length factor, L, of the USLE indicated a negative relationship with soil loss. However, because the plots were all quite small, it is unlikely length would be a significant factor (Foster et al., 1981). Predictions for rangelands on an event basis were poor. Relatively good predictions were made on the tested mine spoil areas, which had a range of slopes from flat to steep. Rainfall simulator (3) mentioned above was used in the mine spoil tests.

I collected extensive data on over-winter rill erosion on seeded fields of winter wheat along a 45-mile transect across the Palouse in eastern Washington and northern Idaho. The area is characterized by steep slopes, and erosion is considered to result primarily from runoff. A rill meter (McCool et al., 1981) was used to collect the soil loss data at the end of the winter erosion season.

During data collection in the late winter after several erosion events, there was little evidence of the head cutting or extensive undercutting of the sides of the channels which are commonly seen when a high-intensity storm releases a large volume of water in a short period. The data were corrected for differences in soils and crop management by use of soil erodi-

bility factors (Wischmeier et al., 1971) and soil loss ratios (Wischmeier, 1973). The soil erodibilities were determined from data from soil survey maps. The soil loss ratios were calculated as products of residue, growing cover, surface roughness, and antecedent soil moisture factors. Soil loss was calculated on a projected area basis, and horizontal slope lengths were used in all calculations. Relationships between corrected soil loss and slope length and steepness were fit by regression techniques.

Because the data were collected from rills alone formed under low intensity rainfall and snowmelt conditions, rainfall energy should have little influence on the data. Steepness of local or segment lengths of slopes ranged from 3 to 53 percent slope. The bulk of the data was collected from slopes of 20 to 40 percent. A fit of all the data collected from 1973 through 1976 showed the relationship:

$$A \propto \lambda^{0.45}\, s^{0.69} \tag{35}$$

or

$$A \propto \lambda^{0.45} (\sin\,\theta)^{0.73} \tag{36}$$

where A = average soil loss per unit area,
λ = horizontal length of slope,
s = slope steepness, percent, and
θ = slope steepness, degrees.

There was little difference between coefficients of determination for the two relationships. The regressed sum of squares attributable to slope length was much greater than the regressed sum of squares attributable to slope steepness. The results were found to be sensitive to the assumptions for soil erodibility and soil loss ratio, and hence are preliminary and subject to future revision as better estimates of soil erodibility and soil loss ratio are made.

DISCUSSION

The literature concerning the influences of slope length and steepness on erosion is characterized by a wide divergence between results of past and current research. The influence of slope steepness exhibits the wider range in both theory and results. Most data have been collected on cropland plots or in laboratory flumes of less than 20 percent slope. Renner, Foster and Martin, Packer, Gregory, Utah Water Research Laboratory, Trieste and Gifford, and I studied or considered steep slopes such as those frequently encountered on rangelands, forest lands, mine spoil areas, and construction sites. However, only Renner, Packer, and Trieste and Gifford collected or reported data from rangeland sites.

Quasi-theoretical analyses have frequently been based on empirical uniform flow relationships such as the Manning formula. A force balance is written, and the shear stress exerted by an element of water on a unit of the bed is considered the force causing detachment. There is generally little agreement either in theory or in result as to the value of the exponent to which this shear force should be raised to properly calculate detachment and transport under a given set of conditions. Foster et al.

(1977a) presented theory and evidence that this exponent is related to the relative amounts of sheet and rill erosion, and to the amount of headcutting and undercutting taking place in the rill system. The rill erosion data that I collected under low runoff rates where there is little headcutting or undercutting support this concept.

Only the small-scale laboratory study of Foster and Martin (1969) indicates that, within the range of commonly encountered slope steepness, the influence of slope steepness peaks and then decreases if other variables remain constant. Gregory and Steichen (1978) used this data in an extensive analytical development to consider the influence of surface bulk density on erosion. They reproduced several sets of existing length and steepness data with the resulting relationship. Yet the results were only hypothetical because the actual surface bulk densities of these soils were not known. I applied the Gregory and Steichen relationship to the rill erosion data collected from Palouse wheat fields. Using the mean bulk density of 1.28 gm/cm^3, measured at 1 in depth, I obtained a curve quite close to the fitted curve. This was rather unexpected because the rill data were collected from conditions where the influence of raindrop impact, the basis of Gregory's bulk density correction, should be minimal.

Packer's rainfall simulator data from 6-ft-long plots on rangeland of 33 to 66 percent slope indicated no influence of slope steepness on runoff or erosion. Trieste and Gifford's analysis of small plot rainfall simulator data from rangeland indicated a slope steepness exponent of about 1.

If rangelands are in good condition and headcutting and undercutting of rills are absent, and particularly if erosion processes are such that soil loss is mostly by sheet erosion, it seems reasonable, based on evidence presented by Foster et al. (1977a) and Young and Mutchler (1969), that exponents of 2 for slope steepness are too large. Indeed, most sheet erosion seems to vary with slope steepness to an exponent less than 1. Preliminary analysis of the data that I collected in the field from rills formed under low rainfall and runoff rates where headcutting and sidewall undercutting are generally absent indicates a range of exponents of from 0.55 to 0.95, for either percent slope, s, or sin θ, with a composited value of 0.7 for 4 years of data.

RECOMMENDATIONS

Based on the limited data from various sources, it is proposed that rangelands, forest lands, and construction slopes be considered in three categories for slope steepness effects on erosion:

<u>Category I</u>. Those areas with good cover condition in climatic zones where no concentrated rilling is expected under conditions of large rates and volumes of rainfall and runoff. Category I might also include situations where there is rilling but where there is little or no depression storage, and runoff is independent of slope steepness. Palouse wheat fields are an example. Certain construction sites may be included here. Until more adequate theory can be developed and data collected to validate the theory, I suggest the following relationships:

Slopes less than or equal to 9 percent:

$$A \propto 0.43 + 30 \sin\theta + 430 \sin^2\theta. \tag{37}$$

Slopes greater than 9 percent:

$$A \propto \sin\theta. \tag{38}$$

where A = average soil loss per unit area
θ = slope steepness, degrees

Category II: Those areas with fair cover condition or in climatic zones where moderate rates and volumes of rainfall and runoff with only moderate rilling are expected or observed, or both. These essentially include areas intermediate between Categories I and III below. Examples would be areas with only infrequent high-intensity thunderstorms but where rainfall is sufficient to support fair vegetation cover. I suggest the following relationships:

Slopes less than or equal to 9 percent:

$$A \propto 0.43 + 30 \sin\theta + 430 \sin^2\theta. \tag{39}$$

Slopes greater than 9 percent:

$$A \propto 30 \sin\theta + 125 \sin^2\theta. \tag{40}$$

Category III: Those areas with poor or deteriorated cover condition or in climatic zones where concentrated rilling from large rates and volumes of rainfall and runoff is observed or expected, or both. These might include steep mine spoils during the time of vegetation establishment in areas with a high incidence of high-intensity rainstorms. Category III would also include situations where runoff is related to slope steepness through roughness and depression storage effects. Until more adequate theory can be developed and data collected to validate the theory, I suggest the Wischmeier-Smith relationship (1978):

$$A \propto 0.43 + 30 \sin\theta + 430 \sin^2\theta. \tag{41}$$

Values of a slope steepness factor S calculated from equations (37) through (41) for slopes from 0.5 to 100 percent are presented in Table 1; curves are plotted in Figure 1. Values of S are ratios of predicted sheet and rill erosion to that for a 9 percent slope. For a 100 percent (45°) slope, the values of the S factor in Categories I, II, and III are 7.9, 22.7, and 36.0, respectively. Slopes greater than 100 percent are seldom encountered in the field. At slopes of this magnitude, soil movement is more likely to be by mass movement processes rather than by rainfall and runoff-caused surface erosion.

Less research has been conducted on the influence of slope length on erosion than on the influence of slope steepness on erosion. Cropland plot studies on slopes of less than 20 percent indicated a power relationship ith an exponent between 0 and 0.9. A value of 0.5 for slopes of greater

than 5 percent was suggested by Wischmeier and Smith (1965) and is widely used. To my knowledge, mine is the only field data collected on the influence of slope length for slopes greater than 20 percent. This data, collected from rills alone, indicated an exponent value of 0.45. This was somewhat unexpected following the reasoning of Foster et al. (1977a) which indicates average rill loss might vary linearly with slope length. However, I did not attempt to determine a critical value of slope length below which rill erosion might be negligible. Determination of such a critical length would raise the value of the slope length exponent in equations (35) and (36).

Based on previous cropland investigations and on my steep slope cropland investigations, I suggest that for rangelands the Wischmeier-Smith (1978) relationship for slope length be used:

$$A \propto \lambda^m \tag{42}$$

where A = soil loss per unit area,
λ = horizontal length, and
m = 0.5 if percent slope is 5 or more, 0.4 on slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent, and 0.2 on uniform slopes of less than 1 percent.

A combined length and steepness factor, LS, for rangelands would then be:

Category I. No observed or expected rill erosion:

Slopes less than or equal to 9 percent:

$$LS = \left(\frac{\lambda}{72.6}\right)^m (0.065 + 4.56 \sin\theta + 65.41 \sin^2\theta). \tag{43}$$

Slopes greater than 9 percent:

$$LS = \left(\frac{\lambda}{72.6}\right)^m 11.16 \sin\theta. \tag{44}$$

Category II. Moderate rainfall and runoff rates and moderate rilling:

Slopes less than or equal to 9 percent:

$$LS = \left(\frac{\lambda}{72.6}\right)^m (0.065 + 4.56 \sin\theta + 65.41 \sin^2\theta). \tag{45}$$

Slopes greater than 9 percent:

$$LS = 8.12 \sin\theta + 33.8 \sin^2\theta. \tag{46}$$

Category III. Rill erosion from high rainfall and runoff rates:

$$LS = \left(\frac{\lambda}{72.6}\right)^m (0.065 + 4.56 \sin\theta + 65.41 \sin^2\theta). \qquad (47)$$

where LS = slope length and steepness factor relative to a 72.6 ft slope length of uniform 9 percent (5.1^{o}) slope,
λ = horizontal slope length, feet,
θ = slope steepness, degrees, and
m = 0.5 if percent slope is 5 or more, 0.4 on slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent and 0.2 on uniform slopes of less than 1 percent.

When working with steep slopes, the difference between slope length and horizontal length must be considered. Rainfall energy and intensity are calculated on a projected (horizontal plane) area basis as well as are field or watershed areas and erosion or sediment yield. Any length determinations made from aerial photos or USGS maps are made on a horizontal basis. Therefore, horizontal length and horizontal area are to be used in all length and steepness relationships. Any field measurements made along the slope should be corrected to horizontal length before erosion predictions are made. With the availability of inexpensive scientific calculators, this is not a major obstacle to field personnel.

Nonuniformly sloped areas are frequently encountered in the field, on both natural and disturbed areas. Erosion estimates can be adversely influenced if a uniform slope steepness is assumed on complex slopes. Procedures have been developed for improving erosion estimates for nonuniform slopes. A discussion of the range of conditions under which nonuniform slope procedures must be used is beyond the scope of this manuscript. A complete description of the procedures is given in Agriculture Handbook 537 (Wischmeier and Smith, 1978).

CONCLUSION

Data on the effect of slope length and steepness on soil loss from rangelands are virtually nonexistent. If accurate predictions of soil loss from rangelands are needed for range resource maintenance or water quality purposes, a program of data collection will be needed. The most rapid means of collecting this data will be with rainfall simulators larger than those previously used.

In the interim, I suggest that rangelands be classified as Category I (no observed or expected rill erosion under large rates and volumes of rainfall and runoff), Category II (moderate rainfall and runoff rate and moderate rilling observed or expected), and Category III (rill erosion expected from high rainfall and runoff rates), and that equations (43) through (47) be used for predicting the influence of slope length and steepness on erosion.

Because there is little data to support the relationships in equations (43) through (47), and because of the wide range of values for slope steepness factor at slopes above 20 percent calculated from them, the equations

are offered for field use on a trial basis and to elicit response from resource management personnel and researchers. If comments and discussion are favorable, this manuscript will be offered for publication in a more strictly reviewed journal. Comment and discussion can only stimulate further research and speed the development of better-substantiated relationships.

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TABLE 1.--Tentative Slope steepness factors for rangeland

Percent slope, s	Category[1] I	Category[2] II	Category[3] III
0.5	0.089	0.089	0.089
1	0.12	0.12	0.12
2	0.18	0.18	0.18
3	0.26	0.26	0.26
4	0.35	0.35	0.35
5	0.46	0.46	0.46
6	0.57	0.57	0.57
8	0.85	0.85	0.85
10	1.11	1.14	1.17
12	1.33	1.45	1.54
14	1.55	1.78	1.96
16	1.76	2.13	2.42
20	2.19	2.89	3.48
25	2.71	3.96	5.02
30	3.21	5.13	6.78
40	4.14	7.68	10.8
50	4.99	10.4	15.2
60	5.74	13.1	19.7
70	6.40	15.8	24.2
80	6.97	18.3	28.4
90	7.46	20.6	32.4
100	7.89	22.7	36.0

[1]No rill erosion observed or expected.

[2]Moderate rainfall and runoff rates and moderate rilling observed or expected.

[3]Rill erosion from high rainfall and runoff rates.

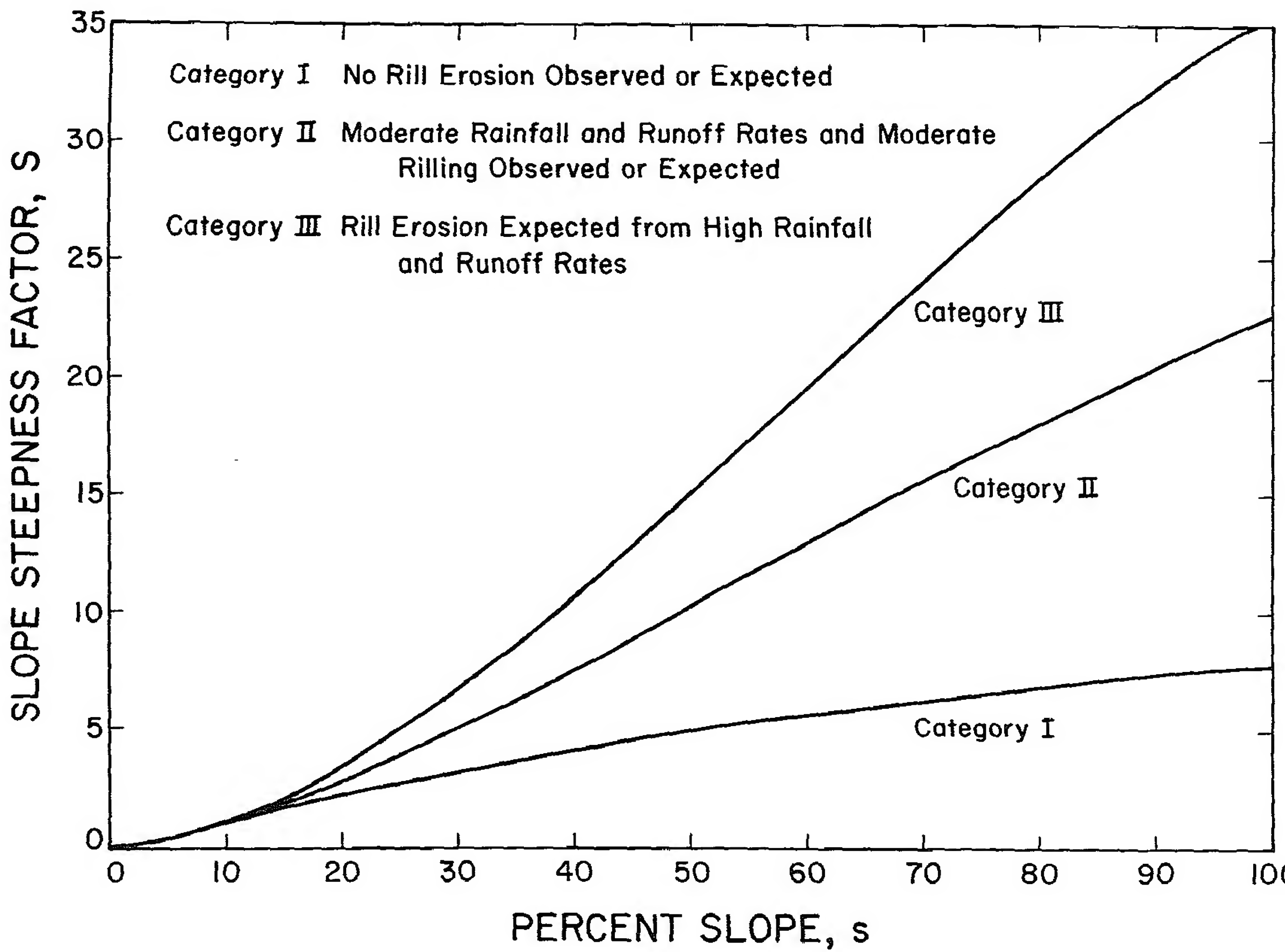

Figure 1--Tentative slope steepness factors for rangeland

SPECIAL PROBLEMS IN THE APPLICATION OF THE USLE TO RANGELANDS: C AND P FACTORS[1/]

G. R. Foster[2/]

ABSTRACT

The Universal Soil Loss Equation (USLE) is being used to estimate erosion on rangeland in the Western United States. This is a new application of the USLE, and values for the cover-management factor C and the supporting practices factor P are being used that were derived from data principally obtained from Eastern U. S. cropland soils and covers. Consequently, research is needed to validate the currently used C and P values and to develop new values where necessary. Development of C and P values for Western rangeland will need to include identification of the influencial factors affecting erosion on rangeland, and evaluation of the effects of erosion pavement, cover, nonuniformity of cover, roughness, soil disturbance, roots, freezing and thawing, burning, infrequent and intense storms, and ridges, pitting and other mechanical treatments on runoff and erosion.

INTRODUCTION

The C (cover-management) factor is the single most important factor of the USLE when the sensitivity of computed soil loss to each USLE factor is considered. Factor values range from less than 0.005 to slightly greater than 1.0 and are affected by many variables, some of which are difficult to measure. If soil loss is 20 tons/acre for C = 1.0, then soil loss is 0.1 tons/acre for C = 0.005 if none of the other USLE factors change.

Existing C factor values for agricultural land and construction sites were developed from much natural and simulated rainfall plot data, but a similar data base does not exist for rangelands. Published C factor values (Wischmeier and Smith, 1978) frequently used for rangelands were derived from relationships for basic subfactors for the effects of canopy, ground cover, soil consolidation, and plant roots on erosion. Data for these relationships were obtained mainly from studies of the effects of straw, cornstalk, and

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2/ Hydraulic Engineer, USDA, and Associate Professor, Agricultural Engineering Department, Purdue University, West Lafayette, Indiana.

stone mulches on erosion from plots on cropland and construction sites and from studies of natural runoff from grassed plots. While the relationships have sound experimental bases and appear to give reasonable results, the derived C factor values have never been validated specifically for rangelands. Values for C published in Agriculture Handbook No. 537 (Wischmeier and Smith, 1978) do not apply to all situations likely to be encountered on rangelands. Root plowing is one situation where C factor values are not available. Recently Dissmeyer and Foster (1981) developed C factor relationships for forest land that may apply to rangeland, but their relationships also need validation specifically for rangeland.

The P (supporting practices) factor describes the effect of supporting practices like contouring, stripcropping, grass buffer strips, and terraces on erosion. The P factor was primarily evaluated from data from small agricultural watersheds. Values of P for a given practice were determined by taking the ratio of soil loss from a watershed having the given practice to the soil loss from a similar watershed not having the practice. The available data were limited, and only general effects of supporting practices were defined. Of the USLE factors, P is the one that is most poorly defined and validated. It is also the most variable factor for seemingly identical situations.

PROBLEMS

The list below identifies problem areas related to the application of USLE C and P factors to rangelands.

1. Influencial factors. What are the key factors in Western rangeland situations that influence erosion? The USLE is typically used as an inventory tool to identify serious erosion problems, and used as a management tool to guide the selection of practices to adequately control erosion. The USLE must reflect the influence of cover type and density, grazing practices, and mechanical treatments on erosion. However, the trend in erosion evaluation is to identify subfactors and their effects. For rangelands, some subfactors are obvious such as cover, erosion pavement, and roughness, but the complete set of subfactors affecting erosion on rangeland must be identified. Their effects must be quantified and related to easily recognized features of common plant communities, grazing practices, and mechanical treatments. Can information obtained from erosion studies on cropland and forest land in the Eastern United States be transferred to Western rangeland?

2. Erosion pavement. In some locations, selective erosion over many years by either wind, water, or both has left a gravelly surface cover that protects the soil from erosion. How effective is this pavement and how should its effect be described -- in the soil erodibility factor K or in the cover-management factor C? The curve in Agriculture Handbook No. 537 for the effect of surface cover was developed mainly from data for surface straw mulch. Does this curve apply to an erosion pavement?

3. Cover. Cover is often the best single protection against erosion. What are the characteristics of various kinds of cover that affect erosion, how much do they affect erosion, and how are factor values related to

plant characteristics that are easily measured and classified? Is percent ground cover an adequate measure for all types of surface cover, or is stone less effective than plant litter for the same percent cover?

4. Nonuniform cover. Cover on some rangeland can be highly scattered and nonuniform. Some vegetation may be elevated above runoff on pedestals of sediment trapped from wind erosion. In other cases, the soil directly beneath some plants appears to be susceptible to erosion while the area between plants is protected by an erosion pavement. How can these effects be described, and how do they vary during the year? Are the size of bare areas and their relative positions important, or is percent cover alone an adequate measure of the effectiveness of ground cover?

5. Roughness. Rangeland treatments, such as root plowing, and grazing can create roughness which can reduce erosion. What is the effect of roughness and how long does it persist?

6. Soil disturbance. Root plowing and livestock traffic can expose and loosen soil and construction can remove an erosion pavement, all of which tends to increase erosion. How great are the effects of these soil disturbances and how long do they persist?

7. Roots. Roots tend to hold soil particles together and provide organic matter when they decay. The role of roots, especially on Western rangeland, is incompletely understood, although the assumed effect in the C factor values frequently used on rangelands is great.

8. Freezing and thawing. Freezing and thawing occur on much Western rangeland. Does this loosen soil making the soil more erodible? Does it offset adverse affects from soil consolidation by trampling of cattle? Some soils appear to be especially susceptible to erosion by rain when they are thawing. Knowledge on this effect is very incomplete. Furthermore, C factor values for the thawing period or for erosion by snowmelt could be quite different from those for other periods when erosion is by raindrop impact and surface runoff from rainfall.

9. Burning. Obviously burning removes cover which increases erosion. Also, burning over some soils greatly reduces their infiltration capacity which increases runoff and erosion. What are the factors responsible for the decreased infiltration and how important are they in the USLE?

10. Infrequent storms. Storms in many parts of the West are highly nonuniform in time and space, which has a bearing on the applicability of the USLE (Trieste and Gifford, 1980). Do infrequent and highly variable storms require C factor values that are more accurate with respect to specific conditions at the time and location of the storm than are required in the Eastern U. S.? What is the significance of antecedent conditions in the West, and how can that significance be described in the USLE, if it is important?

11. P factors. Sometimes ridges, steps, and cowtrails develop on rangeland and divert runoff from a direct downslope path. When can these conditions be expected, what are their effects, and how can their effects be

described in the USLE? These features often reduce soil loss by reducing transport capacity of the runoff, and since the USLE is primarily an erosion equation, is a separate equation needed to describe the influence of these features on transport capacity? As a two-phase process, should a transport capacity equation be used to estimate the sediment load moving through the transport-limiting area where deposition occurs and should the USLE be used to estimate the sediment load delivered to the deposition areas (Neibling and Foster, 1977)?

12. Interaction of USLE factors. With two major exceptions, the USLE factors are generally assumed to be independent of each other. Values for C depend on the distribution of erosivity R over the year, and the slope-length exponent decreases with slope steepness below 5 percent. Several other potential interractions exist. The slope length exponent depends on relative amounts of rill and interrill erosion. A particular practice may be more effective on a soil susceptible to rill erosion than on one that is not susceptible to rill erosion. Therefore, C values might be different for the two soils. Significant improvement in estimating soil loss would likely require an erosion equation that considers interrill and rill erosion as separate terms. Furthermore, another equation would be required for conditions where transport capacity limits soil loss. The influence of interactions could be directly computed with these new equations.

13. Relation of USLE factors to runoff. Erosion is related to runoff because runoff may detach soil and runoff is the dominant sediment transport agent. Even though values for the USLE erosivity factor are computed solely from rainfall variables, all of the USLE factors implicitly contain a runoff effect. For example, the C factor includes the effect on erosion of a reduction of runoff by a management practice. Erosion estimation for specific storms could be improved if the relation of runoff to erosion was better understood, and if the runoff effect in all USLE factors was known.

CONCLUSIONS

These problems illustrate the need for expanded research in the West to validate existing or to develop new values for the USLE C and P factors. Two major research needs seem apparent. The first is to develop factor values for particular rangeland conditions. The second is to identify the influence of individual factors that can be used in a subfactor approach to estimate C and P for a given condition. A productive research approach is to conduct experiments that simultaneously contribute to both research needs. Of the problems listed above, my opinion is that the effects of cover including both vegetal and stone, the nonuniform distriution of cover, soil roughness, and soil disturbance are the most important study topics for immediate research.

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A TEST OF THE USLE ON BARE AND SAGEBRUSH PLOTS IN UTAH

George E. Hart[1/]

STUDY AREA

In June, 1980 a rainfall simulator (Lusby 1977) from the BLM Special Service Project, Denver, Colorado was used on eight "standard" plots (72.6 x 6 feet) to evaluate factors in the Universal Soil Loss Equation (USLE) on rangelands. Due to limited time, only two conditions were examined: (1) low intensity rainfall (about 1.1"/hr for 60 minutes) on dry soil followed by (2) high intensity rainfall (about 2.2"/hr for 33 minutes) on very wet soil. The simulator had rainjet sprinkler heads which procuded a D_{50} of 1.75 mm at 28 psi; intensity was changed by adding additional sprinkler risers to the delivery system. Rainfall intensity was held constant through each event and monitored by a recording gage and can gages. Plots were bordered, and all runoff and sediment were collected in a large tank. Total oven-dry weights of sediments were obtained.

The study area is situated about 20 miles northeast of Logan, Utah at an elevation of 6200 feet. The soil is a silt loam, typic argixeroll, a common soil in mountains of northern Utah, and a K value of .32 was assigned from the nomograph using particle-sizes from lab analysis. Four plots were on a gentle slope (11%), and four were on a 32% slope about 100 yards away.

Three surface conditions existed on the plots, both on gentle and steep sites:

Fallow: Bare soil produced by cutting sagebrush, removing roots, and rototilling (6" deep) up and downslope. Root wads and larger stones removed by raking. Tilling was done four times over a 3-year period preceeding the test, one of which was a week before the test. The surface was not as rough as would be produced by agricultural tillage, but a C factor of 1.00 was assigned (four plots total).

Crusted: Sagebrush removed, rototilled, and raked once in 1977. Regrowth killed by herbicide in 1978 and 1979 (not rototilled). A slightly compacted surface layer (1/4") has developed. Surface rock cover, about 1" diameter or less, occupies 15% on gentle slope and 32% on steeper plot. C assumed to be 1.00 (two plots total).

Vegetated: Sagebrush/grass cover, not grazed for 3 years but probably some residual compaction effect from former light-moderate grazing. Seventy-

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[1/]Watershed Science Unit, Utah State University, Logan, Utah 84322.

five to 78% cover 1/2 meter high plus 5 to 11% surface litter. Table 10, Agriculture Handbook 537, was used to get C = .015 and .020.

RESULTS

Data on rainfall application, runoff, infiltration rate at the end of the run, and total soil loss per "storm" are shown in Table 1. In all runs, except two made during windy conditions, our actual rates of rainfall application were reasonably close to the desired rates of 1.1 and 2.2"/hr. Due to limited water supply and storage tank capacity, we could maintain the 2.2"/hr rate for only 33 minutes. It is apparent that exceptionally low surface runoff and high infiltration rates occurred from runs on dry, fallow plots. This suggests that equilibrium conditions were far from being satisfied. Soil losses from the crusted plots always exceeded those from the fallow plots. Table 2 compares soil loss predicted by the USLE with measured loss. Factor values K = .32, P = 1, and LS = 1.351 on 11% slope and 7.4 on 32% slope were used. Rain energy was calculated both by the (916 + 331 log I) method and directly by kinetic energy obtained from the drop diameter distribution of this simulator. Predicted losses were closer to measured losses when KE was used as an index to R, thus supporting the idea that kinetic energy is a more appropriate representation of rainfall erosivity when simulating individual storms.

Table 1.--Intensity, runoff, and soil loss from erosion plots in northern Utah

	Condition	Intensity	Duration	Rainfall	Runoff	Runoff rainfall	Infiltration capacity	Soil loss
		(in/hr)	(min)	(in)	(in)	(%)	(in/hr)	(T/ac)
				Low Intensity Rain on Dry Soil				
	Fallow	1.00	60	1.00	.02	2.2	.97	.024
Gentle slope	Fallow	1.08	60	1.08	.01	1.3	1.06	.005
(10-11%)	Crusted	.79	60	.79	.04	5.0	.71	.043
	Vegetated	1.33	50.7	1.12	.01	.5	1.32	.004
	Fallow	1.46	61	1.48	.04	2.9	1.30	.146
Steep slope	Fallow	1.10	58.5	1.07	.01	.6	1.09	.011
(31-32%)	Crusted	1.12	58.5	1.09	.25	23.2	.76	4.814
	Vegetated	1.20	60	1.20	.01	.6	1.19	.006
				High Intensity Rain on Wet Soil				
	Fallow	2.14	33	1.18	.42	35.8	.94	2.846
Gentle slope	Fallow	2.00	18	.60	--	--	.54	2.338
(10-11%)	Crusted	2.03	33	1.11	.69	61.9	.52	5.115
	Vegetated	2.30	33	1.26	.02	1.5	2.26	.010
	Fallow	2.27	33	1.25	.41	32.5	1.32	11.504
Steep slope	Fallow	2.28	33	1.26	.54	43.0	--	9.513
(31-32%)	Crusted	2.33	33	1.28	.78	60.9	.85	12.982
	Vegetated	2.40	33	1.32	.02	1.4	2.37	.028

Table 2.--Comparison of predicted and measured soil loss

		Antecedent moisture	Intensity	Predicted[1/] loss E	KE	Measured loss	Difference[2/] EI_{30}	KE
		(%)	(in/hr)	(-----tons/acre				-----)
				Low Intensity Rain on Dry Soil				
	Fallow	--	1.00	3.96	2.42	.02	+ 3.9	+ 2.4
Gentle slope (10-11%)	Fallow	10	1.08	4.67	3.05	.01	+ 4.6	+ 3.0
	Crusted	--	.79	2.38	1.19	.04	+ 2.3	+ 1.1
	Vegetated	6	1.33	.09	.06	.004	+ .09	+ .06
	Fallow	11	1.46	49.66	42.41	.15	+ 49.5	+ 42.3
Steep slope (31-32%)	Fallow	11	1.10	25.93	16.69	.01	+ 25.9	+ 16.7
	Crusted	4	1.12	26.95	17.64	4.81	+ 22.1	+ 12.8
	Vegetated	4	1.20	.64	.46	.006	+ .63	+ .45
				High Intensity Rain on Wet Soil				
	Fallow	41	2.14	11.18	7.21	2.85	+ 8.3	+ 4.4
Gentle slope (10-11%)	Fallow	47	2.00	5.26	1.75	2.34	+ 2.9	- .6
	Crusted	32	2.03	9.82	6.06	5.12	+ 4.7	+ .9
	Vegetated	37	2.30	.20	.13	.010	+ .19	+ .12
	Fallow	36	2.27	69.48	47.03	11.50	+ 58.0	+ 35.5
Steep slope (31-32%)	Fallow	31	2.28	70.40	48.05	9.51	+ 60.9	+ 38.5
	Crusted	24	2.33	73.26	50.63	12.98	+ 60.3	+ 37.6
	Vegetated	26	2.40	1.56	1.11	.028	+ 1.53	+ 1.08

[1/] Soil loss predicted from USLE using two methods for estimating rain energy, E: $E = (916 + 331 \log_{10} I)$ and $KE \approx \frac{1}{2} MV^2$. Other values in the USLE are the same.

[2/] Overestimates indicated by +, underestimates by -.

In all tests except one, the USLE overestimated soil loss from the bare plots, and often, the errors were substantial (from 20 to 60 tons/acre, depending on how R was calculated). Actual losses from vegetated plots were miniscule, and the USLE predicted correspondingly small losses. Prediction was better for the higher intensity events on wet soil. This implies that conditions of higher intensity rainfall on moderately wet soils on gentle slopes better approximate conditions under which the factors in the USLE were originally developed. But these are not the prevailing conditions of soil moisture and slopes on western rangelands.

A third observation that can be made from Table 2 is that prediction is poorer on the steeper site than on the gentle site for all surface conditions. Because all plots were of standard length, the weakness is probably in the slope factor. For these uniform slopes, LS values of 1.35 and 7.4 were used from the slope-length chart (Agriculture Handbook 537); this factor was 5.5 times greater on the 32% slope than on the 11% slope. Measured losses on both the dry runs and wet runs averaged only 4.0 times greater on the 32% slope with

all other factors the same.

The most difficult factor to properly index was the C factor. This is the most sensitive element in the USLE because of the extremely wide range (1000-fold) of possible values. A rough idea of the appropriateness of C values (Table 10, Agriculture Handbook 537) used in this study can be obtained by "backward" solution of the USLE using measured values of soil loss as A and finding the cover factor, C', necessary to obtain the measured loss.

For sagebrush/grass cover, computed C' values were:

Gentle Slope	C'
Dry soil; low rainfall intensity	.001
Wet soil; high intensity	.003
Steeper Slope	
Dry soil; low intensity	.001
Wet soil; high intensity	.002

These calculated values are quite consistent and are about 10 times smaller than the values of .015 to .020 obtained from the table. The vegetation management method of combining subfactors of canopy (Type I), litter (Type II), and residual fine roots (Type III) produced a C factor of .12. Although, perhaps, a 10-fold overestimate may result from incorrect assessment of the C factor at very high cover densities, the absolute values of errors in tons/acre are small and are not very important in a land management context.

At the other end of the scale are bare, or nearly bare, conditions which are extremely important in wildland environments as potential nonpoint sources of sediment pollution. Such conditions are common and are caused by wildfire, road construction, some logging practices, severe overgrazing, concentrated recreational activities, landslides, and surface mining. Again, by backward solution of the USLE using measured soil loss as the A term, we obtain the following C' values for completely bare surfaces:

Gentle Slope		C'
Dry soil; low intensity	Fallow	.006
	Crusted	.022
Wet soil; high intensity	Fallow	1.20
	Crusted	1.90
Steep Slope		
Dry soil; low intensity	Fallow	.007
	Crusted	.33
Wet soil; high intensity	Fallow	.63
	Crusted	.76

The low calculated C' values (.006, .007, .002, and .33) for low intensity rain on dry fallow or crusted surfaces indicate that a C value of 1.00 overestimates soil losses under dry conditions substantially. When plots were wet, calculated C' values were closer to 1.00 (.63 and 1.20 for fallow plots and .76 and 1.90 for crusted plots). The disparity in C' between dry and wet soil conditions indicates that antecedent moisture is not adequately indexed by the conventional methodology of the USLE. Original development of the factor values for K and C were based on long-term annual measurements of soil loss in a more humid region than the intermountain region. Thus, we find a closer approximation of calculated C' values to 1.00 for bare surfaces with wet soils.

C' values were always higher for plots with crusted surfaces than for those rototilled fallow plots. If a C value of 1.00 is assumed for bare, fallowed surfaces, a value for the chemically bared, undisturbed surface of 1.2 to 1.6 would be appropriate. C values of 1.2 to 1.3 have been proposed for highway construction sites which are scraped and compacted by bulldozer.

CONCLUSIONS

Limited tests of the USLE were made on standard plots on a mountain rangeland site in Utah using a rainfall simulator. Although far from conclusive, the tests point to several problems which may be important when using the USLE on range and forestlands in the West.

1. Closer prediction of measured soil loss occurred for higher intensity rainfall (about 2.2"/hr for 33 minutes) on previously wetted bare soil than for lower intensity rain on very dry soil. Effects of antecedent moisture can be important and are not taken into account for individual events.

2. Existing tables, or methods, for determining K values and C values (particularly C values in the bare, fallow condition) do not adequately represent wildland soils and cover. The substantial overestimates by the USLE seem mostly attributed to these factors.

A major research need is to establish baseline values of soil losses per unit of R under standard conditions of a bare, but uncultivated, surface.

USE OF RAINFALL SIMULATORS TO DETERMINE PARAMETERS FOR EROSION PREDICTION

John M. Laflen[1/]

INTRODUCTION

Rainfall simulators are necessary to determine Universal Soil Loss Equation (USLE) parameters for a rapidly changing, unpredictable agriculture. For example, we are going to need cropping management factors for narrow-row, no-till soybeans in the Corn Belt within five years. If we produce oil from sunflowers in the Corn Belt, we'll need estimates of cropping management factors at various crop stages for several tillage systems.

Presently, we can make reasonable estimates of the value of various factors in the USLE for many conditions. These can be validated, if sufficien natural-rainfall erosion studies have been conducted. In today's era, the scientist or research organization seldom can collect data without a clearly defined, specific purpose, nor, can the data collection period much exceed five years. The rainfall simulator is a necessary tool (some say a necessary evil) in empirical and basic studies of soil erosion.

There are several models of rainfall simulators. In this paper, I'll discuss studies in which "larger" (plots with a minimum of 10 m length) simulators that have rainfall energies and intensities near that of natural rainfall are used. I will not attempt to review the many papers dealing with the attributes of various rainfall simulators; much of this has been reported by others (Meyer and McCune, 1958; Meyer, 1960, 1965; Mech, 1965; Mutchler and Hermsmeier, 1965; Palmer, 1965; Swanson, 1965; Bubenzer and Meyer, 1965; USDA, 1979).

My objective is to summarize the methods and procedures that others have used in determining USLE parameters by using rainfall simulators. Simulators have been used most for soil erodibility and cropping management factors and, to a much lesser extent, for length-slope factors. This review will be confined to soil erodibility and cropping management studies.

1/John M. Laflen is an Agricultural Engineer with the Science and Education Administration, U.S. Department of Agriculture, Ames, Iowa, 50011.
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SOIL ERODIBILITY STUDIES

The rainfall simulator has been used extensively to collect soil erodibility data (Wischmeier and Mannering, 1969; Wischmeier et al., 1971; Barnett et al., 1965; Young and Mutchler, 1977; Barnett and Rogers, 1966; Romkens et al., 1975; Barnett et al., 1971; Barnett and Dooley, 1972; and Dangler et al., 1976). Plot preparation in nearly all studies has consisted of removing existing vegetation, tillage that included disking and inversion of the soil, and until the tests were performed, continued tillage (usually disking) to control vegetation.

Rainfall simulator storms have been somewhat similar. Most storms have been at 6.4 cm/hr. Barnett et al. (1971) in a Puerto Rican study applied one storm at 12.7 cm/hr. They also simulated a "hurricane" storm at an intensity of 30.5 cm/hr.

Storm sequences have varied somewhat. Most studies have involved two storm periods about 24 hr apart. Wischmeier and Mannering (1969) applied a 60-min storm at 6.4 cm/hr, and then, about 24 hr later, applied two 30-min storms, 15 min apart, both at 6.4 cm/hr. Young and Mutchler (1977) followed a very similar arrangement, except on the second day, their rain was continuous for 1 hr. Dangler et al. (1976) followed a similar procedure, except that they applied 2 hr of continuous rainfall on each of two consecutive days. Barnett et al. (1965) and Barnett and Dooley (1972) applied a similar amount of rainfall (2 hr at 6.5 cm/hr) as did Wischmeier and Mannering (1969), but there were four 30-min storms with 10 min between storms.

Most data have been adjusted by using USLE length-slope and cropping management factors. Although the length-slope adjustment may involve little judgment, selection of the appropriate cropping management factor would be difficult and subject to considerable judgment.

Wischmeier and Mannering (1969) and Barnett and Rogers (1966) did not use USLE factors for data adjustment. Barnett and Rogers reported their data as unadjusted soil loss/EI and related this to a number of independent variables. Wischmeier and Mannering related soil loss from each storm for all plots to a number of independent variables. When an equation that explained more than 95 percent of the plot-to-plot variance for that storm was derived, the equation was solved for soil loss expected from that storm for each plot by using unit plot specifications and average values of time-dependent variables.

Soil erodibility values have been determined in several different ways by using adjusted data from a series of rainfall simulator storms. Wischmeier and Mannering (1969) regressed soil loss on EI for each soil in their study on 55 soils. They had four data points for each soil representing individual storms and combinations of individual storms. The erodibility value for a soil was defined as the slope of the regression line. Barnett et al. (1971) also determined soil erodibility values by using a similar regression method, but on data adjusted by using USLE adjustments.

Wischmeier et al. (1971) used data from the study by Wischmeier and Mannering (1969), except for four soils, to develop the soil erodibility

nomograph. However, they weighed the adjusted soil loss (adjusted to unit-plot conditions by using generally accepted relationships) to place soil erodibility values "more nearly on an annual basis." They did this by computing a K based on soil loss and EI by combining 13 of the first, 7 of the second, and 3 of the third storm. Barnett et al. (1965) and Young and Mutchler (1977) also weighted their storms to arrive at an annual K-value, but their weightings were different from those of Wischmeier et al. (1971). Weightings were selected on the basis of the climate of the regions where the data were collected.

CROPPING MANAGEMENT STUDIES

The rainfall simulator has been used extensively to study the effect of cropping and tillage on soil erosion. (Meyer et al., 1970; Mannering and Meyer, 1963; Mannering and Meyer, 1961; Mannering et al., 1966; Mannering and Johnson, 1969; Mannering et al., 1964; Mannering et al., 1968; Swanson et al., 1965; Wischmeier, 1973; Young et al., 1964; Siemens and Oschwald, 1978; Johnson and Moldenhauer, 1979; Moldenhauer et al., 1971; Laflen et al., 1978; Laflen and Colvin, 1981). Studies have been conducted on plots treated nearly like a typical cropped field and on plots where treatments did not resemble those for a typical field.

Field-sized machinery usually is used where prepared plot conditions need to be similar to the field condition for the treatments under study. Most studies are performed up-and-down hill so that the unknown effect due to contouring on small plots can be eliminated (Meyer, 1960). Some studies have been on the contour (Siemens and Oschwald, 1978; Wischmeier, 1973; Swanson et al., 1965).

A large number of the studies have been performed by using a common storm arrangement of a 60-min storm, followed about 24 hr later by two 30-min storms separated by a 15-min period, all at an intensity of 6.4 cm/hr. There seems to be little particular reason for this procedure, other than that it gives a good range of antecedent moistures.

Other storm arrangements have included a constant rainfall intensity until runoff achieves a constant rate (Siemens and Oschwald, 1978; Laflen and Colvin, 1981). Wischmeier (1973) used two 60-min storms separated by a 15-min period.

Generally, studies have been conducted at an intensity of about 6.4 cm/hr. Exceptions would include those of Swanson (1965), Moldenhauer et al. (1971), Young et al. (1964) and Laflen et al. (1978). All these but Young et al. had a 1.4 hr rainfall at 6.4 cm/hr, and, the next day, had a 1-hr rainfall of 6.4 cm/hr followed by either a 0.3- or 0.5-hr storm at 12.7 cm/hr. Young et al. (1964) applied rainfall at 3.2 cm/hr for 0.5 hr and then at 6.4 cm/hr for another 0.5 hr. About 24 hr later, they applied another rainfall of 3.2 cm/hr for 0.5 hr, 6.4 cm/hr for 0.25 hr, and then 3.2 cm/hr for 0.5 hr.

Cropping management factors have not been directly computed from rainfall simulation results, even though all the factors involved in determination of

a C-value are measured in most studies. C-values are derived on the basis of the ratios of soil loss from the treatment to soil loss from a treatment with a given C-value. This procedure reduces the effect of antecedent moisture, which makes it difficult to directly compute accurate C-values. I have directly computed C-values for some studies. These values vary widely for similar treatments and crop stages on different soils and slopes.

TOWARD NEW METHODS

Erosion prediction in the future will be based more on fundamental, as opposed to empirical, relationships derived on the basis of mathematical descriptions of the erosion process. Currently, the erosion process is described as rainfall detachment and transport (interrill erosion) and runoff detachment (rill erosion) and transport. The USLE is an excellent tool for describing the effect of major factors on soil erosion from a user's viewpoint, but, to provide reliable information quickly, the more basic relationships are needed to generate values for use in the USLE and for tying together the impact of practices on sediment yields downstream. Likely, the concepts presented by Foster et al. (1977a, b) will serve as a useful framework for research for several years. Experiments will be most useful that collect data to fit into these basic models.

The Foster et al. (1977a) model gives the interrill detachment rate as

$$D_i = K_i\ I(bS + c) \qquad (1)$$

where K_i is a soil erodibility term for interrill erosion, I is a measure of the potential for raindrop impact and interrill flow to detach and transport soil, S is slope steepness, and b and c are coefficients. Rill detachment (D_r) is given as

$$D_r = a_s\ (\zeta_e - \zeta_{cr})^{\zeta} \qquad (2)$$

where a_s is a factor relating to the surface's susceptibility to rill detachment, ζ_e is effective shear stress, ζ_{cr} is a critical shear stress, and ζ is a constant. Foster et al. assumed ζ_{cr} to be zero and assumed ζ had a value of 3/2. It was then possible to derive an erosion equation of the form

$$G = X^2\ K_r(aS^e)F_tC_rP_r + XK_i(bS + c)I_tC_iP_i \qquad (3)$$

where X is slope length, K_r is a rill erosion soil factor, S is slope steepness, F_t and I_t are runoff and rainfall erosivity factors, C_r and C_i are cropping management factors for rill and interrill erosion, P_r and P_i are supporting practice effects on rill and interrill erosion, a, b, c, and e are coefficients and G is total sediment load from X. By dividing by X, erosion in terms of mass/area is given. Considerable simplification has occurred to arrive at these equations.

We have been conducting rainfall simulation studies where data are collected to use in Equation 3 and so that parameters are acquired for the USLE.

In these studies, erosion is expressed as the erosion from the lowest length L of a longer lengh X. On L, a rainfall simulator is used and flow is added at the upper end of L to simulate the flow from (X-L). From Equation 3, erosion measured on L can be written as

$$G_L = (2XL - L^2)(K_r aS^e F_t C_r P_r) + K_i (bS + c)\ I_t C_i P_i L \tag{4}$$

where L is plot length, and G_L is the total erosion load from L. If Equation 4 is valid and the only factor changing is the simulated length X, then,

$$G_L = a' + b'X \tag{5}$$

where

$$b' = 2LK_r aS^e F_t C_r P_r \tag{6}$$

and

$$a' = K_i (bS + c) I_t C_i P_i L - K_r aS^e F_t C_r P_r L^2 \tag{7}$$

Some of our work is reported by Hussein (1978).

Generally, results where flow is added at different rates at the upper end of a runoff plot during rainfall simulation have been good. Water has been added at the end of the usual rainfall simulation when runoff rates are a constant. The simulation is continued without interruption and water is added uniformly across the upper end of a plot. When flow rates equilibrate at the lower end of a plot, flow rates are measured, and samples collected. Flow onto the upper end is increased, and the process repeated. This is continued until the maximum plot length desired has been simulated.

Flow rates being added at the upper end, (q_a) are measured. If the runoff flow rate at the end of the regular simulation is q_s, the length being simulated (X) is given as

$$X = L\left(1 + \frac{q_a}{q_s}\right) \tag{8}$$

where L is plot length. Water is added in such a manner that scouring due to the mechanism of flow addition is minimized. The maximum length simulated is generally in the order of 10 times the plot length (L).

We have simulated lengths in studies involving fallow plots, row-crop plots at several stages of growth, and small-grain plots. The only time that we've felt uneasy about the results have been on fallow plots at high slopes when we've caused tremendous erosion. In some of these cases, the erodibility of the soil has changed because of deep rilling. Under most cropped conditions, we've found that Equation 5 fits our data nicely. We have had good success relating the slope of Equation 5 to residue cover, but poor success in relating the intercept to residue cover. There is considerable variability in this type of data, and intercepts cannot always be estimated reliably.

SUMMARY

I've tried to review a wide enough range of papers to give the reader a range of experiences regarding procedures for plot preparation, rainfall simulation and data adjustment. No universal procedures can be recommended for plot preparation, rainfall simulation, or data adjustment, for these must be determined for the study conditions and based on application of the study results. I have focused my review on studies in which simulators have been used on plots at least 10 m long.

No one (at least that I have found) has reported cropping management factors for the USLE directly from a rainfall simulation study. Values are generally relative to a treatment having a known C-value.

Studies should be designed and conducted to gain data for mathematical models describing the erosion process. We have found length simulation during rainfall simulation to be highly useful.

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ESTIMATING SEDIMENT YIELD FROM RANGELAND WITH CREAMS[1/]

G. R. Foster L. J. Lane[2/]

ABSTRACT

The erosion/sediment yield component of CREAMS, a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, may be used to estimate sediment yield from small rangeland watersheds. The component operates on a storm-by-storm basis using rainfall erosivity, runoff volume, and a characteristic runoff rate. It applies to a broad range of management practices and considers the influence of topographic features on erosion and deposition along concave, convex and complex slopes; deposition by backwater at field outlets; and erosion and deposition in natural and constructed waterways. Enrichment of the sediment by fines is computed when the model computes deposition. Validation studies have shown that the model gives reasonable results for agricultural areas with little or no calibration.

INTRODUCTION

CREAMS, a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems (USDA, 1980), may be used to estimate sediment yield from small rangeland watersheds. The model has three separate components: (i) hydrology, (ii) erosion/sediment yield, and (iii) chemistry. The hydrology component estimates runoff amount, peak runoff rate, and storm erosivity using data for daily, hourly, or breakpoint rainfall. Runoff estimates from daily rainfall are based on the SCS curve number method and those from hourly or breakpoint rainfall are based on a modification of the Green-Ampt infiltration equation (Smith and Williams, 1980). The chemistry component describes the movement of soluble and sediment-adsorbed plant nutrients (Frere et al., 1980), pesticides, herbicides, and other similar chemicals (Leonard and Wauchope, 1980) from field-sized areas.

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2/ Hydraulic Engineer, USDA, and Associate Professor, Agricultural Engineering Department, Purdue University, West Lafayette, Indiana; and Hydrologist, USDA, Southwest Rangeland Watershed Research Center, Tucson, AZ.

The erosion/sediment yield component of CREAMS (Foster et al., 1980c) was orginally developed for agricultural fields but has sufficient generality to apply to rangelands, disturbed forest areas, construction sites, and surface mines. The component also applies to a broad range of conservation practices including conservation tillage, rotations, contouring, stripcropping, terraces, grassed waterways, and small impoundments. It considers the influence of topographic features on erosion and deposition along concave, convex, and complex slopes; deposition by backwater at field outlets; and erosion and deposition in natural and constructed waterways. The model has overland flow, concentrated flow, and impoundment components to represent the major hydrologic, hydraulic, erosion, deposition, and sediment transport processes on field-sized areas. Both absolute and relative erosion and sediment yield estimates for a specific site and practice are reasonably accurate (Foster et al., 1980a; Foster and Ferreira, 1981). Parameter values require little or no calibration, and their selection is relatively easy (Foster et al., 1980b). Since the model uses runoff volume, rainfall erosivity, and a characteristic runoff rate to compute an average sediment concentration for each storm, computer time required to simulate a record of 20 or more years of individual storms is much less than that required by a similar fully dynamic model that time-steps through each storm.

BASIC RELATIONSHIPS

The model computes detachment, sediment transport, and deposition on a storm-by-storm basis. Quasi-steady flow is assumed, and sediment is routed through overland flow and concentrated flow areas.

The basic equation of the model is for continuity and is given by:

$$dq_s/dx = D_L + D_F \qquad [1]$$

where q_s = sediment discharge, x = distance, D_L = rate of lateral inflow of sediment, and D_F = rate of detachment or deposition by flow. Rate of deposition D_d is given by:

$$D_d = \alpha(T_c - q_s) \qquad [2]$$

where T_c = transport capacity and the coefficient α is given by:

$$\alpha = a\, V_s/q \qquad [3]$$

where a = 0.5 for overland flow and 1.0 for concentrated flow, V_s = fall velocity of a sediment class, and q = rate of runoff. Sediment transport capacity is estimated with the Yalin equation (Yalin, 1963; Foster and Meyer 1972) modified for nonuniform sediment (Foster et al., 1980c). Flow hydraulics are computed with the Manning equation, and shear stress is distributed between ground cover and the soil according to sediment transport theory. The shear stress acting on the soil is that portion of the total shear stress that is responsible for sediment transport.

Sediment is assumed to be detached as a mixture of several classes of primary particles and aggregates. The model computes the segregation of the classes and enrichment of fines during deposition (Foster et al., 1980d).

Detachment on overland flow areas is computed separately for interrill erosion, which is principally by raindrop impact, and rill erosion, which is principally by flow, by using a modification of the Universal Soil Loss Equation (Wischmeier and Smith, 1978; Foster et al., 1977; Foster et al., 1980b). Detachment by concentrated flow in waterways is computed with an excess shear-stress type equation where the critical shear stress is a function of soil type, tillage, and recency of tillage (Foster et al., 1980b). Deposition in small impoundments where outflow is controlled by an orifice is described with an exponential relationship that is a function of sediment fall velocity, impoundment geometry, infiltration within the impoundment, and orifice diameter (Foster et al., 1980c).

APPLICATION TO RANGELANDS

The erosion/sediment yield component of CREAMS can be applied to small rangeland watersheds. The same general size limitations that apply on cultivated agricultural areas also apply on rangelands. Watershed areas are limited in size by the assumption of uniform rainfall and runoff. Soil, cover, and topography may vary along the slope, but not laterally within the watershed. The channel network is represented by a simple main channel or a main channel and several, similar contributing channels analogous to a terrace channel system or furrows in row crops contributing to an outlet channel. The size of the area to which the erosion/sediment yield component of CREAMS applies varies with the situation, but 100 acres is a general upper limit.

The model can be used to evaluate erosion and sediment yield under current conditions and under proposed alternative managment practices such as different grazing intensities, different types and percentages of vegetative cover, and different surface roughnesses and soil disturbances from mechanical treatments such as root plowing. CREAMS can also describe the influence of slope shape, especially its effect on deposition on concave slopes and increased erosion on steep portions of convex slopes, and the variation in erosion and deposition due to changes in soil, cover, and roughness along a slope. The model can also be used to estimate erosion or deposition in waterways or channels within small watersheds. The effects of spatially varied flow in channels is simulated to account for the influence of changes in channel slope, increase of flow rate in the downstream direction, and localized flow controls at the outlet that cause backwater. Such controls can significantly reduce transport capacity, causing a great reduction in sediment yield due to deposition by the backwater immediately upstream of the control.

An advantage of CREAMS for application to Western rangeland is that it more accurately estimates erosion and sediment yield for individual storms than does the Universal Soil Loss Equation. This is especially important because a very few, even one or two, storms can dominate annual erosion for many Western sites. CREAMS is also more accurate than the USLE for surfaces where transport capacity limits sediment yield because CREAMS treats transport

separate from detachment, while the Universal Soil Loss Equation lumps these two separate processes together.

Application of CREAMS to rangeland is not without difficulty because values for some parameters are either unknown or have not been validated for certain conditions. For example, soil erodibility factor values have not been measured for many Western soils. Also, the effects on erosion processes of erosion pavement and clumped, isolated vegetation have not been evaluated. Critical shear stress and channel erodibility factor values are not readily available for natural channels in rangelands. However, CREAMS is a state-of-the-art erosion model. These same difficulties exist with other erosion models (Foster, 1981) that might be used. New parameter values specifically for rangelands can readily be used in CREAMS as soon as research defines them.

SUMMARY

The erosion/sediment yield component of CREAMS, a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, with elements for overland flow, concentrated flow, and small impoundments, can be used to estimate erosion and sediment yield from rangelands. It operates on a storm-by-storm basis using rainfall erosivity, runoff volume, and a characteristic runoff rate. Sediment is routed downslope using equations for continuity, detachment or deposition, and sediment transport capacity. Sediment is assumed to be composed of both primary particles and aggregates.

Validation studies have shown that the model can give reasonable results for agricultural conditions with little or no calibration. The same is expected for rangelands, particularly after research more precisely defines parameter values for soil erodibility, erosion pavement, and other features unique to Western rangelands.

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MODELING EROSION IN OVERLAND FLOW

L. J. Lane and E. D. Shirley[1/]

INTRODUCTION

Overland flow on a plane is a function of time and space and is often modeled using the kinematic wave equations (Henderson and Wooding 1964; Wooding 1965a, 1965b, and 1966). A kinematic flow number, as a criterion for accuracy of the kinematic approximation to the unsteady flow equations, was developed by Woolhiser and Liggett (1967), who found that the approximation was accurate under conditions representative of many overland flow surfaces (Woolhiser 1974). The kinematic wave equations were derived for flow on smooth planes but have been shown to apply on many irregular surfaces where the mean velocity per unit width is proportional to the storage in an incremental area. Such surfaces include simple upland areas typical of many natural watersheds (Woolhiser, Hanson, and Kuhlman 1970).

Erosion on upland areas is conceptionalized as rill and interrill erosion (Foster and Meyer 1971; Foster, Meyer, and Onstad 1977). Interrill erosion is assumed due to impact of raindrops and associated transport overland. Rill erosion is assumed due to soil detachment and subsequent transport by flow in rills or small channels. Hjelmfelt, Piest, and Saxton (1975) give a partial solution to the coupled runoff and erosion equations that are described herein.

THE MODEL

The kinematic wave equations for overland flow on a plane are:

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = R, \qquad (1)$$

and

$$q = Kh^m \qquad (2)$$

where h, q, and R are, respectively, the depth of flow, runoff rate per unit width of the plane, and rainfall excess rate. The coefficient K is a parameter including slope and roughness, and m is an exponent reflecting the flow type (laminar or turbulant) and the roughness-velocity relationship (Manning or Chezy equation)

Given overland flow as described above, interrill erosion rate is assumed as

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[1/] Hydrologist and mathematician, USDA-SEA-AR, Southwest Rangeland Watershed Research Center, 442 East Seventh Street, Tucson, Arizona 85705.

$$E_I = K_I R \tag{3}$$

and rill erosion rate is assumed as

$$E_R = K_R(Bh^a - q_s) \tag{4}$$

where K_I, K_R, and B are, respectively, interrill coefficient and rill coefficients. The exponent a is usually assumed equal to m, which also facilitates solution of the equations. The sediment discharge per unit width of the plane is

$$q_s = cq \tag{5}$$

where c is sediment concentration. Notice that the variables defined by Eqs. 1 thru 5 are functions of time, t, and distance, x, down the plane.

Using the above equations, Shirley and Lane (1978) derived a sediment yield equation by integrating, with respect to time, the sediment continuity equation

$$\frac{\partial(ch)}{\partial t} + \frac{\partial q_s}{\partial x} = E_I + E_R \tag{6}$$

to produce a sediment yield equation as a function of position on the plane. The resulting equation for sediment yield per unit width of the plane, $Q_s(x)$, as a resultant of constant and uniform rainfall excess is

$$Q_s(x) = Q(x)\ [\frac{B}{K} + (K_I - \frac{B}{K})(\frac{1 - e^{-K_R x}}{K_R x})] \tag{7}$$

where Q(x) is runoff volume per unit width of the plane, and the other variables are described earlier. Equation 7 expresses the influence of slope length (x) on sediment yield in overland flow.

PARAMETER ESTIMATION

The runoff model has two parameters, K and m. Procedures for estimating K, and thus determining m, are summarized in Table 1. Under circumstances where observed runoff data are available, optimal parameters can be determined by fitting simulated runoff rates to corresponding observations. The parameters to be determined for the erosion equations are K_I, K_R, and B. These could also be estimated using optimization and available sediment concentration data.

Concentration as a function of t and x has been derived and evaluated to produce three equations in three unknowns (Shirley and Lane, 1978, Eqs. 28 thru 30). Initial concentration $C_o = C(t = o,x)$ can be estimated by extending observed sediment concentration data back to the t = o axis on a plot of concentration versus time. Mean concentration can be estimated as the observed sediment yield divided by the observed runoff volume $\overline{C} = Q_s/Q$. Also, the final concentration, C_∞, can be estimated by extending the plot of observed sediment concentration through the hydrograph recession until the end of the event on a plot of concentration versus time.

Table 1.—Hydraulic resistance parameters for steady-state turbulent flow over the indicated surface (after Woolhiser, 1974 and Lane et al., 1975)

Overland flow surface: Roughness condition	Type	Approximate range in resistance parameters[1]: Manning[2] n	Chezy[3] C
Very smooth	Concrete, asphalt	0.010 - 0.013	60 - 45
Smooth	Bare sand	0.010 - 0.016	60 - 37
	Eroded bare soil, small gravel	0.012 - 0.033	50 - 20
Moderate	Sparse vegetation, rangeland	0.050 - 0.130	14 - 5.7
High	Short grass prairie, good grass	0.100 - 0.200	7 - 4
Very high	Dense grass, sod	0.170 - 0.400	4.5- 2

[1]English units are used in this table and in the references cited.

[2]For turbulent flow, K becomes: $K = \frac{1.49}{n} S^{1/2}$, $m = 5/3$.

[3]For turbulent flow, K becomes: $K = CS^{1/2}$, $m = 3/2$.

The corresponding equations from the model are:

$$C_o = K_I, \tag{8}$$

$$\overline{C} = \frac{B}{K} + (K_I - \frac{B}{K})(\frac{1 - e^{-K_R x}}{K_R x}), \text{ and} \tag{9}$$

$$C_\infty = \frac{B}{K} + (K_I - \frac{B}{K})e^{-K_R x} \tag{10}$$

Given estimates of C_o, C, and C_∞ from the observed data, they are set equal to the corresponding values from Eqs. 8 thru 10, and the resulting equations are solved simultaneously for K_I, K_R, and B.

APPLICATION TO RANGELANDS

Data used are from the Walnut Gulch Experimental Watershed operated by the U.S. Dept. of Agriculture. A detailed description of this research facility is given by Renard (1970). Generally, surface runoff on Walnut Gulch results from short duration thunderstorms during the summer rainy season. The area is described as semiarid rangeland.

To satisfy the model assumptions, a rainfall simulator was used to obtain runoff and sediment concentration data from a small plot. In addition, data were selected from a 1.3-ha watershed on the Walnut Gulch Experimental Watershed (Shirley and Lane 1978; Smith 1976). The plot data were used to test the

derived solutions for consistency and reasonableness with observations. The watershed data were used to test the solutions for consistency and to determine if the model might have applications for natural watersheds.

The rainfall simulator used is a portable version of the Colorado State University apparatus (Dickinson, Holland, and Smith 1967). The portable simulator is described in detail by Lusby and Toy (1976). The artificial rainfall is produced at a rate of about 50 mm/hr. Analysis of drop-size distribution and raindrop velocities indicated that the artificial rainfall has about 30% to 40% of the kinetic energy of natural rainfall (Neff 1978). This reduction in rainfall energy is reflected in the interrill erosion parameter, as discussed later.

A 22.1 by 6.1 m plot (Lucky Hills Plot) was instrumented to obtain continuous runoff records and sediment concentration data at 1-min intervals throughout the overland flow hydrographs. The plot had a slope of 7% and closely approximated an overland flow plane. By making a series of closely spaced runs on the plot, it is possible to approximate the constant, uniform rainfall excess pattern assumed in obtaining solutions to the equations. This procedure was followed to obtain data from the runoff plots. The plot was established in an undisturbed area adjacent to Watershed 63.101, described below. In a preliminary effort to calibrate the rainfall simulator, a 22.1 by 9.1 m plot (Montijo Plot), with a slope of 2%, was instrumented. Limited runoff and sediment data were also obtained from this plot.

Examples of rainfall, runoff, and sediment concentration data for the Montijo and Lucky Hills plots are shown in Fig. 1. Also shown in Fig. 1 are the resulting simulated hydrographs and sediment concentration graphs for the runoff-erosion model. These two events were selected to show cases where the runoff peak rate was under and overestimated, and where there was a relatively poor and good fit, respectively, to the observed sediment concentration data.

Optimal parameters (K, K_I, K_R, and B) were determined for each of nine events from the Lucky Hills Plots, as summarized in Fig. 1. As stated earlier, the product of the runoff volume and mean concentration, $Q\,\bar{c}$, is the sediment yield for the individual event:

$$Q_s = Q\,\bar{c} = Q\left[\frac{B}{K} + \left(K_I - \frac{B}{K}\right)\left(\frac{1 - e^{-K_R x}}{K_R x}\right)\right] \tag{11}$$

where Q_s is sediment yield in kg and Q is runoff volume in m^3. The regression equation relating computed sediment yield, Y, and observed sediment yield is:

$$Y = -0.007 + 1.09 Q_s \tag{12}$$

with $R^2 = 0.99$. Equation 12 represents a very good fit, although the optimal parameters were determined from fitting sediment concentration data instead of total sediment yield. Using the mean values of the optimal parameters ($K = 1.66$, $K_I = 0.87$, $K_R = .19$, and $B = 0.027$) results in the regression equation:

$$Y = -0.017 + 1.58\ Q_s \tag{13}$$

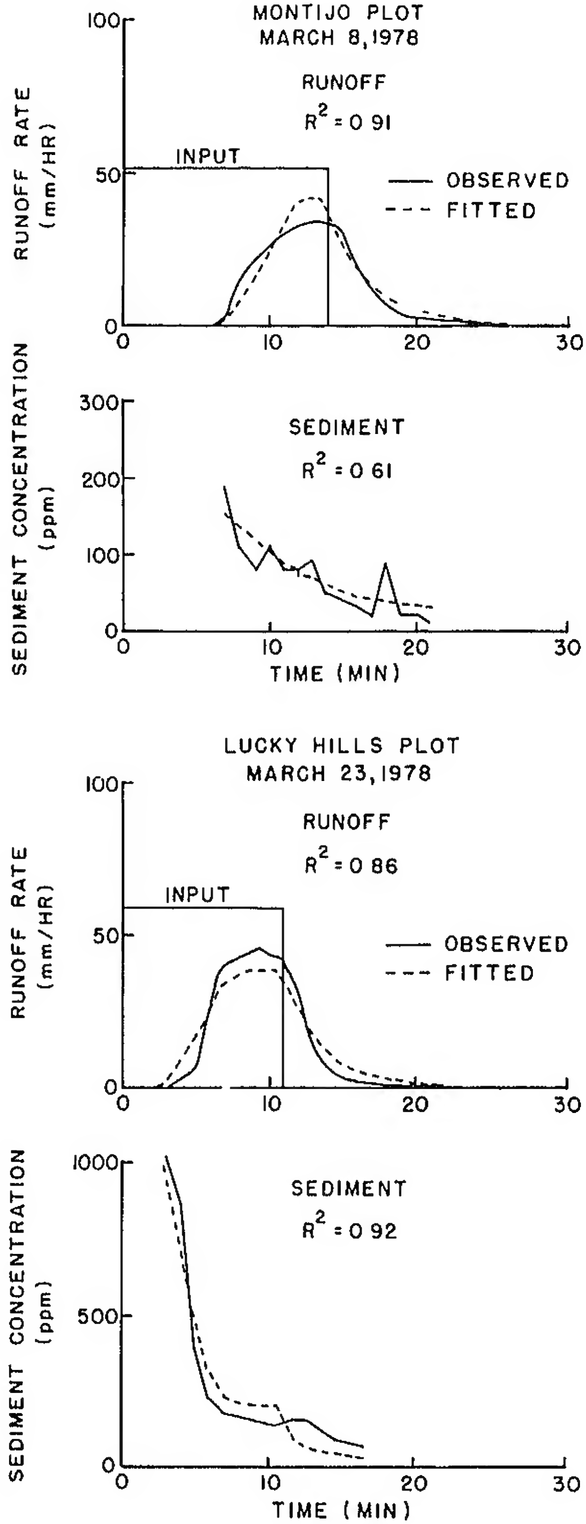

Figure 1.--Examples of observed and fitted data, rainfall simulator.

with $R^2 = 0.99$. The coefficient in this equation represents a significant bias in the computed sediment yields. Therefore, the means of the optimal parameters from fitting individual events produced larger errors than were obtained by letting the parameters vary from event to event.

Simulated concentration data matched the observed sediment concentration data quite well (Fig. 1) and, using optimal parameter values, computed sediment yields compared favorably with observed sediment yields. Thus, the runoff-erosion model appears to adequately simulate overland flow and erosion on the experimental plots.

A small (1.3-ha) watershed, called Lucky Hills Watershed 1 (63.101), was selected for additional analysis. This watershed is instrumented with a recording raingage, broad-crested v-notch weir, and a water-level recorder. During periods of ephemeral flow, pump-type (suspended sediment) samples are taken at 3-min intervals throughout the duration of runoff. This 1.3-ha watershed was approximated as a plane of length 194 m, width of 67 m, and a total relief of 7.8 m. A more complex representation of this watershed was presented by Smith (1976) wherein the watershed was represented by overland flow planes contributing to a small channel. Smith's simulation results agreed quite well with measured runoff and sediment yield data. However, his simulated raindrop splash detachment rates exceeded the amounts estimated from observed data, especially later in the storm events.

During the period 1973 to 1975, rainfall, runoff, and concentration data were obtained from 13 runoff events. Of these, eight events with single- peaked hydrographs were selected for analysis. In addition, a ninth event with a small secondary peak was included, because it was the largest event of record, and it provided an extreme.

As stated above, simulated hydrographs were computed for each of the nine events. The sum of squared deviations in runoff rate was used as the objective function. Optimal runoff parameters (K, R, t_*) were determined. Rainfall excess rate is R, and t_* is the duration of rainfall excess. Values of R and t_* were computed to reproduce the observed volume of runoff for each event. Optimal concentration parameters (K_I, K_R, B) were also determined (using the optimal runoff parameters as fixed values).

The equation (corresponding to Eq. 12) relating observed and fitted sediment yield is:

$$Y = 8.2 + 0.89\ Q_s \tag{14}$$

where $R^2 = 0.99$. The equation using mean values of the optimal parameters ($K = 3.69$, $K_I = 4.39$, $K_R = 0.032$, and $B = 1.31$) is

$$Y = 54.7 + 0.90\ Q_s \tag{15}$$

with $R^2 = 0.98$. Again, using mean rather than individual values for the parameters resulted in reduced fitting accuracy.

Optimization results for the Lucky Hills Plot and for Watershed 63.101 are summarized in Table 2.

Table 2.—Mean values of optimal parameters for the Lucky Hills Plot and for Watershed 63.101 (Note: m = a = 3/2)

Watershed	Drainage Area	K	K_I	K_R	B
	(ha)	($m^{1/2}$/sec)	(kg/m^3)	(m^{-1})	($kg/sec\text{-}m^{2.5}$)
Lucky Hills Plot	0.014	1.66	0.87	.19	0.027
63.101	1.30	3.69	4.39	.032	1.31

The natural watershed had a hydraulic resistance parameter of K = 3.69, while the plot had a value of K = 1.66 for an average increase in flow velocity coefficient of 3.69/1.66 = 2.2. The interrill parameter, K_I, increased by a factor of 5 from the plot to the natural watershed. As discussed previously, we might expect a 2- to 3-fold increase due to rainfall energy considerations. The product K_RB represents a rill erosion parameter. This product increased by a factor of 8 from the plot to the watershed. Interpretation of the changes in these parameters from the plot to the watershed suggest that : (1) flow velocities increased, (2) interrill erosion rates increased, and (3) rill erosion rates increased. Since we were not modeling the channel network on Watershed 63.101 and the simulated rainfall had significantly less energy than natural rainfall, these parameter changes are in the direction expected. However, since they are mean values of parameters determined from limited data, the changes should be given only qualitative interpretations.

SUMMARY AND CONCLUSION

Runoff from upland areas can be accompanied by substantial erosion. We modeled overland flow on upland areas as overland flow on a plane. Erosion on upland areas is conceptualized as consisting of rill and interrill erosion. Interrill erosion is assumed due to rainfall impact, and rill erosion was defined as erosion due to tractive forces and transport capacity in flow as it occurs in rills or small channels. The combined runoff-erosion process is called overland flow with rill and interrill erosion.

Partial differential equations have been formulated for the above runoff-erosion process. Solutions had been developed for the specific cases of the rising and equilibrium hydrographs (Hjelmfelt, Piest, and Saxton 1975). We developed analytic solutions for the general case of rising, equilibrium, and recession hydrographs and for the entire partial-equilibrium hydrograph (Shirley and Lane 1978).

The runoff-erosion model was tested using rainfall simulator data. Optimal values of the model parameters were determined for 9 runoff events. Simulation results with the optimal parameters seem to be reasonable approximations (good fit) to observed runoff and concentration data. Sediment yield values computed by the model also seem to be reasonable approximations to observed data.

To determine if the coupled runoff-erosion equations might have applications for natural watersheds, data from a small, natural watershed on Walnut

Gulch were analyzed. The computed sediment concentration and sediment yield data were consistent with observations on this watershed. The parameter values were logically related to parameters from the experimental plots, and thus, the procedure may have application to small watersheds.

The major result of this research is the derivation and testing of analytic solutions for sediment concentration and sediment yield in overland flow. Based upon our analysis of the properties of these solutions, we conclude that the runoff-erosion model used in this study produces reasonable results for erosion on upland areas. Limited testing with observed data supported this conclusion.

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SEDIMENT YIELD FROM SMALL SEMIARID RANGELAND WATERSHEDS

K. G. Renard and J. J. Stone[1/]

INTRODUCTION

Sediment yield, the quantity of sediment moving past a cross-section of a channel in a specified time interval, is sometimes mistakenly assumed to be synonomous with erosion. Material removed from a slope as rill and interrill erosion may be deposited at the toe of a slope, on a flood plain, or at other points within the watershed where the sediment load exceeds the transport capacity of the runoff. Within a channel, material eroded not only from the landslope, but also from the channel bed and banks and from gullies and headcuts, can be a significant part of the sediment transported past a point on the stream. The path that a soil particle takes in moving to a point of lower potential energy is complicated, and the process is often stepwise in time.

Assuming that governing equations for such movements are known, these complexities make physically based equations describing the movement of sediment difficult to use. Thus, more simplified empirical equations are often used. Recent developments in watershed modeling, however, include erosion/sediment transport routines with detailed hydrologic models. These new modeling techniques promise to reflect the effects of different land use and the effects of the variations from year to year resulting from climatic differences. They do, of course, require much more computer time, have different data requirements, and are more expensive to use than the simple empirical models.

Methods for estimating erosion and sediment yield from rangelands are based primarily upon the principles developed in parts of the United States where cultivated agricultural activities are prevalent. Techniques incorporating disturbance of the soil by tillage are not generally applicable to rangelands, so the erosion-estimating techniques must be adjusted to reflect these land use differences for rangelands. Typical problems unique to rangelands are those associated with the different soils (the genesis of western range soils are different from those in humid areas); the existence of erosion pavements (which provide protection from raindrop impact and decrease the shear of water moving over the land); grazing and trampling by animals; and with channel erosion processes which are very important on rangelands.

Renard (1980) detailed seven different methods for estimating sediment yield. Each has different data requirements, vary in complexity, and produce different results. The choice of method depends upon the objective of the investigation. In this further investigation, some sediment yield formulae are

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[1/] Hydraulic Engineer, USDA-SEA-AR and Graduate Student, University of Arizona, 442 E. 7th St., Tucson, AZ, 85705.

tested with sediment yield data from nine small watersheds in the Walnut Gulch Experimental Watershed near Tombstone, Arizona.

METHODS TESTED

Pacific Southwest Interagency Committee Method (PSIAC)

The method developed by the Water Management Committee of the PSIAC (1968) was intended for broad planning rather than for specific project formulation where more intensive investigations are required. Although this method was intended for use in areas larger than 10 mi^2, we tested it here on small watersheds to demonstrate a method that might be readily used to estimate sediment yield within a land resource area (Austin, 1965). Testing the method improves the confidence of the user in selecting parameter values that reproduce observed data.

The method requires using nine factors to determine the sediment yield classification for a watershed. The factors are (A) geology, (B) soils, (C) climate, (D) runoff, (E) topography, (F) ground cover, (G) land use, (H) upland erosion, and (I) channel erosion/sediment transport. Each factor is assigned a numerical value from a rating chart (PSIAC, 1968) which is too long to reproduce here. Descriptive terms for three sediment yield levels (high, moderate, low) for each factor are used to select the numerical value. Summing the rating chart values for the nine factors defines a sediment yield rating classification, which in turn can be converted to the average annual sediment yield using Table 1.

TABLE 1.--Sediment yield classification

Rating	Classification	Annual sediment yield ac-ft/mi^2
> 100	1	> 3.0
75 to 100	2	1.0 to 3.0
50 to 75	3	0.5 to 1.0
25 to 50	4	0.2 to 0.5
0 to 25	5	< 0.2

Numerical values for each of the nine factors range from 25 to minus 10. lthough only three levels are suggested for general use in the rating chart, a otnote states that, if experience so dictates, interpolation between the ree sediment yield levels may be made. Such interpolation was used in this udy.

To assist in interpolation between the classifications of Table 1, The a in Table 1 were converted to equation form. Although such precision was intended for the original method, we felt that such a scheme could provide itional insight into the ability of the technique to reflect differences in observed data. The equation is:

$$Y = 0.0816e^{0.0353X} \quad (1)$$

where Y = annual sediment yield (ac-ft/mi^2)
e = natural logarithm
X = PSIAC rating factor

Dendy/Bolton Method

Dendy and Bolton (1976) derived sediment yield equations having widespread applicability because they used data from over 800 reservoirs throughout the United States to obtain measured sediment yield values. They segregated the data into areas where runoff was either less than or greater than 2 in/yr.

In areas where runoff is less than 2 in, they derived the equation:

$$S = 1280\, Q^{0.46}(1.43 - 0.26 \log A) \quad (2)$$

where S = sediment yield (t/mi^2/yr)
Q = annual runoff (in)
A = watershed area (mi^2).

Because of widely varying local factors, the authors may not have intended for this equation to be used for a specific location. However, the equation does express a rational relationship for sediment yield that seems realistic for conditions encountered in the Southwest.

To estimate the average annual runoff for a watershed, the relationship developed by Renard (1977) for the Walnut Gulch Experimental Watershed was used:

$$Q = 0.4501\, A^{-0.1449} \quad (3)$$

where the terms are as defined above. Substituting Eq. 3 into Eq. 2 gives

$$S = 887\, A^{-.0667}\, (1.43 - 0.26 \log A) \quad (4)$$

To convert the annual sediment yield to ac-ft/mi^2/yr, the sediment deposited was assumed to weighed 80 lbs/ft^3.

Flaxman Method

Flaxman (1972) developed a regression equation for reservoir design on rangeland watersheds in the western United States relating sediment yield to four parameters. His expression is

$$\begin{aligned}\log (Y + 100) &= 6.21301 - 2.19113 \log (X_1 + 100) \\ &+ 0.06034 \log (X_2 + 100) - 0.01644 \log (X_3 + 100) \\ &+ 0.04250 \log (X_4 + 100)\end{aligned} \quad (5)$$

where Y = antilog of [log (Y + 100)] - 100
Y = average annual sediment yield (ac-ft/mi^2/yr)

X_1 = ratio of average annual precipitation (in) to average annual temperature

X_2 = average watershed slope (%)

X_3 = soil particles greater than 1.0 mm (%)

X_4 = soil aggregation index

The parameters express climate and vegetative growth (X_1), topography (X_2) and soil properties (X_3 and X_4). The equation explained about 91% of the variance in average annual sediment yield from 27 watersheds ranging in size from 12 to 54 mi^2 in 10 western states.

Flaxman (1974) modified his original sediment yield prediction equation by adding an additional term to reflect the 50 percent chance peak discharge in csm (cubic ft/sec/mi^2). The revised equation included converting the dependent variable sediment yield from acre-ft in the original equation to ton/mi^2. The equation is thus given as

$$\begin{aligned}\log (Y + 100) &= 524.37321 - 270.65625 \log (X_1 + 100)\\ &+ 6.41730 \log (X_2 + 100) - 1.70177 \log (X_3 + 100)\\ &+ 4.03317 \log (X_4 + 100) + 0.99248 \log (X_5 + 100)\end{aligned} \tag{6}$$

where Y = sediment yield in ton/mi^2 yr,
X_5 = the 50 percent chance peak discharge, csm and
X, X_2, X_3, and X_4 are the same as defined in eq (5).

Renard Method

A method for estimating sediment yield was developed by Renard (1972) and Renard and Laursen (1975). This method uses (a) a stochastic runoff model (Diskin and Lane, 1972) which generates hydrographs for semiarid watersheds in the southwestern United States, and (b) a deterministic sediment tansport relationship (Laursen, 1958). Sediment yield is then computed by simulating individual hydrographs and computing the sediment transport for the simulated hydraulic conditions. Annual runoff and sediment yield is the sum of the yield of individual runoff events. Thus, sediment yield is a function of runoff volume, hydrograph peak, Manning's roughness, slope, hydraulic radius, and the size distribution of the sediment in the streambed. The method was applied and calibrated with sample data for several of the larger watersheds on Walnut Gulch in southeastern Arizona. With the model, a simplified relationship was developed which relates the annual sediment yield to watershed drainage area in the form

$$Y = 0.001846\ A_a^{-.1187} \tag{7}$$

where Y = average annual sediment yield in ac-ft/ac/yr
A_a = drainage area in acres.

Thus, because of transmission losses (abstractions from runoff by the alluvial channels) in the watershed, water yield decreases with increasing drainage area (drainage density), and this same trend is reflected in the sediment yield relationship. Conversions are required to produce the units comparable to the other methods.

Additional improvements might be made with the method if, rather than using the general relationship shown in eq. (7), actual annual runoff volume were used as input to the stochastic simulation routine along with actual bed material size distributions in the channels of the watersheds used for the testing.

MODIFIED UNIVERSAL SOIL LOSS EQUATION (MUSLE)

Williams and Berndt (1977a) have recognized that the erosion estimates of the USLE can be modified to reflect the transport of sediment in runoff and thereby, extend the use of this technique to larger areas. The Modified Universal Soil Loss Equation is given as

$$Y = 11.8\ (Vq_p)^{0.56}(K)(C)(P)(LS) \tag{8}$$

where Y = sediment yield from the basin in Mg
V = the surface runoff volume for the basin in m^3
q_p = the peak flow rate for the basin in m^3/s
K = soil erodibility factor
C = cover and management factor
P = the erosion control practice factor
LS = slope length and steepness factor

Values of K, C, P, and LS may be input for each subbasin if the area is large enough to require spatial variability quantification.

To provide the peak flow and runoff volume estimates required by MUSLE, a hydrologic model was used called SWRRB (Williams and Nicks, 1980). The acronym stands for a "Simulator for Water Resources in Rural Basins."

The major processes included in the model are surface runoff, percolation, return flow, reservoir storage, and sedimentation. Surface runoff is computed in the model from daily rainfall values using the SCS (1972) curve number technique. Basically, SWRRB uses the CREAMS (Knisel, 1980) daily rainfall hydrology option modified for application to large, complex rural basins. The major changes involved are (a) adding a return flow component, (b) expanding the model to allow simultaneous computations on several subbasins, (c) adding a reservoir storage component to assist in evaluating the effects of farm ponds on water yield, (d) adding a weather generating model to provide for longer term simulations, and (e) using a better method to predict peak runoff rate. Although computations for predicting water and sediment yields proceed simultaneously, the hydrologic model provides the necessary inputs for MUSLE to compute sediment yield on a daily basis. Details of the model structure and method of computation are not included here because of space limitations.

WATERSHEDS CONSIDERED

The Walnut Gulch Experimental Watershed is a 58 mi^2 (150 km^2) drainage in southeastern Arizona operated by the Science and Education Administration of USDA to evaluate the effect of land use and conservation practices on water and

sediment yield of arid and semiarid rangelands. The watershed, in the Southeastern Arizona Basin and Range Land Resource Area (Austin, 1965), is typical of the intermountain alluvial areas of the Southwest. Elevations range from 4200 to 6000 ft above mean sea level. Cover is a mixture of brush and grasses with vegetation basal areas less than 10%. Soils are typically calcareous with large amounts of gravel and cobbles. A gravel pavement can develop as the land surface erodes, and in some areas it represents nearly a 100% cover.

Precipitation in the area, which averages about 14 in/yr, is dominated by summer rainfall (about two-thirds of the annual) consisting of high-intensity, short-duration thunderstorms of limited areal extent. Winter storms are generally of greater areal extent and of low intensity, so that runoff is uncommon. The summer air-mass thunderstorms result in high peak flows that generally carry high sediment loads.

Within the watershed, a number of small earthen dams (stock ponds) provide water for the grazing animals. Topographic surveys of the pond storage area have been made, periodically, to determine sediment accumulations. The nine ponds for which such information was available are shown in Table 2 along with data on the characteristics of the watershed area. The ponds generally have enough storage space so that discharge through the emergency spillway is infrequent. Pond 223 spilled more often than the others.

TABLE 2.--Characteristics of stock tanks at Walnut Gulch and of the contributing watersheds

Tank number	Drainage area mi^2	Record length	Soil association[1/]	Vegetation	Measured annual sediment accumulation ac-ft/mi^2
201[2/]	0.170	1960-70 1971-79	Rillito-Karro	Brush Grass	0.49 0.13
207	0.428	1962-77	Rillito-Cave-Tortugas	Brush	0.11
208	0.356	1973-77	Hathaway-Bernardino	Grass	0.13
212	1.316	1964-77	Cave-Rillito-Laveen, and Tortugas	Brush	0.11
213	0.616	1962-79	Graham-House Mountain	Brush/Grass	0.09
214	0.581	1957-77	Hathaway-Bernardino	Grass	0.37
215	0.136	1966-77	Hathaway-Nickel	Brush	0.70
216	0.325	1962-77	Hathaway-Bernardino	Grass	0.51
223	0.169	1962-77	Rillito-Laveen	Brush	0.30

1/From Gelderman (1970).
2/The tank drainage was root plowed and reseeded in 1971.

RESULTS AND DISCUSSION

Tables 3, 4, and 5 summarize the parameter values used in the PSIAC, Flaxman, and SWRRB/MUSLE methods, respectively. The Dendy/Bolton and Renard methods (Table 6) are simple one-parameter equations and, as such, are by far the easiest to use.

Table 3.--Summary of the factor values used to estimate sediment yield with the Pacific Southwest Interagency Committee method (Renard, 1980)

Tank number	Factor values[1] A	B	C	D	E	F	G	H	I	Total	Computed annual sediment yield ac-ft/mi[2]
201 B	5[2]	5	8	2	1	-5	0	10	10	36	0.29
201 G	5	5	8	1	1	0	-10	5	10	25	0.19
207	2	2	8	2	8	-8	- 5	10	5	24	0.18
208	5	3	8	2	1	-5	2	5	0	21	0.16
212	3	5	8	1	1	0	0	10	10	38	0.30
213	2	2	8	2	5	-5	0	5	5	24	0.18
214	5	5	8	2	2	0	2	5	15	44	0.38
215	5	3	8	2	1	-2	0	15	15	47	0.42
216	5	5	8	1	2	0	0	10	5	36	0.28
223	5	2	8	2	0	-5	-5	10	20	37	0.29

[1]The factors are defined on p. 2 of the text.
[2]Some interpolation between the three yield levels defined in the manual was used.

Table 4.--Prediction of sediment yield from watersheds at Walnut Gulch using Flaxman methods (eq. 5 and 6)

Tank number	Factor values[1] X_1[2]	X_2	X_3	X_4	X_5	Annual sediment yield ac-ft/mi[2] Y (eq. 5)	Y (eq. 6)
201	0.192	5.3	72	0	226	-0.180	0.16
207	0.206	6.9	55	0	117	0.049	0.12
208	0.179	8.6	47	0	115	0.313	0.17
212	0.206	5.8	41	0	94	0.142	0.12
213	0.206	11.0	46	0	77	0.375	0.15
214	0.216	8.6	52	0	188	0.154	0.21
215	0.216	8.7	44	0	274	0.249	0.32
216	0.216	12.0	52	0	152	0.341	0.23
223	0.206	9.4	65	0	289	0.085	0.28

[1]Factor values are defined on p. 5 for use in Eq. 5 and 6.
[2]Average temperature at Tombstone is 63.1°F. Some adjustment was made based on elevation differences between the Tombstone weather station and the pond (3° F increase per 1000 ft elevation decrease).

Table 5.--Summary of the parameter values used in SWRRB/MUSLE for the Walnut Gulch watersheds

Tank number	T.C.[1/]	Root zone depth	CN_I[2/]	K[3/]	LS[4/]	C[5/]
	(hr)	(in)				
201	.350	15.98	88.13	0.2	0.90	.08/.015
207	.421	15.98	87.19	0.1	0.98	.026
208	.407	20.08	87.45	0.234	0.99	.033
212	.528	15.98	83.97	0.399	0.74	.026
213	.454	20.94	86.51	0.455	2.89	.026
214	.449	20.08	86.63	0.1	1.63	.040
215	.335	20.08	88.25	0.234	1.33	.027
216	.339	20.08	87.57	0.234	1.94	.030
223	.350	15.98	88.13	0.1	1.83	.040

1/ T.C. = time of concentration. T.C. = $.5A^{.2}$ where A = area in mi^2.
2/ CN_I = from regression. CN_I = 88.75 - .00568A where A = area in acres.
3/ K = soil erodibility factors from the USLE nomograph (Wischmeier and Smith, 1978).
4/ LS = measured from topographic maps using Williams and Berndt (1977b) method.
5/ C = USLE cover/management factor from field measurements; erosion pavement was included in this factor.

In developing the estimates of sediment yield with the Flaxman (1974) method given in eq. (6), the 50 percent chance peak flow was determined by taking the maximum annual runoff volume recorded for each stock pond for which data were available. The 50 percent chance volume was read from the annual flood series using a log-nornal probability distribution. The value was then converted to CSM using the volume/peak flow equation given in the SCS NEH-4 (1972) as follows:

$$X_5 = q_p \frac{640}{A_a} = \frac{484\ AQ}{D/2 + 0.6\ T_c} \left(\frac{640}{A_a}\right) \qquad (9)$$

where: q_p = peak discharge,
A = drainage area (mi^2),
A_a = drainage area (acres),
Q = two year frequency runoff volume (in),
D = storm duration (assumed = 1 hr), and
T_c = time of concentration (hr).

Although the data are not shown, an independent method was also used to estimate parameter X_5 using NOAA Atlas II estimates of the 2-yr frequency 1-hr precipitation depth with an estimate of the watershed curve number and the widely used curve number equation of SCS:

$$Q = \frac{(P-0.2S)^2}{P + 0.8S} \tag{10}$$

where: P = 2-yr frequency 1-hr duration precipitation (in),
S = potential maximum watershed retention (in),
$S = \frac{1000}{CN} - 10$

Estimates of curve numbers (CN's) for the watersheds involved were the same values used in the SWRRB/MUSLE method. The correlation between observed and predicted, using NOAA Atlas II precipitation estimates, was ($r^2 = 0.077$) poorer than that obtained with the log-normal frequency distribution for observed data. It is, however, the method recommended by Flaxman (1974) when data for a specific watershed are not available. The improvement of the estimated sediment yield is dramatic with the addition of the additional parameter. Estimated sediment yield in the absence of observed runoff data tended to overpredict at low sediment yields and underpredict at higher yields, as was observed for all methods.

As can be seen from the summary, Table 6, the PSIAC method generally agreed most closely with the measured data. The PSIAC and MUSLE methods enabled prediction of the change in sediment yield with changes in cover after the treatment of tank 201 in 1970-71. Several individual watershed estimates agree quite well with the observed data.

Table 6.--Measured and predicted annual sediment yield (ac-ft/mi^2) for select semiarid rangeland watersheds (modified from Renard, 1980)

Tank number	Measured yield	Predicted yield					
		PSIAC	Dendy/Bolton	Flaxman[1] (Eq. 5)	Flaxman[1] (Eq.6)	Renard	SWRRB/MUSLE
201 B[2]	0.49	0.29	0.83	-0.180	0.16	0.68	0.25
201 G	0.13	0.19					0.05
207	0.11	0.18	0.73	0.049	0.12	0.61	0.05
208	0.13	0.16	0.75	0.313	0.17	0.62	0.08
212	0.11	0.30	0.62	0.142	0.12	0.53	0.08
213	0.09	0.18	0.69	0.375	0.15	0.58	0.80
214	0.37	0.38	0.70	0.154	0.21	0.59	0.11
215	0.70	0.42	0.85	0.249	0.32	0.69	0.21
216	0.51	0.28	0.76	0.341	0.23	0.63	0.43
223	0.30	0.29	0.83	0.085	0.28	0.68	0.15

[1] Flaxman method includes both eq. 5 and 6 estimates.
[2] The B and G refer to brush and grass cover associated with the 1971 treatment of the watershed.

The values assigned to the nine PSIAC factors were made using some interpolation between the three yield levels defined in the manual. We felt that such interpolation was warranted by our detailed knowledge of the watershed and familiarity with the method (the senior author was a member of the committee which developed the method).

The Flaxman (1972) method, surprisingly, was no better than those of the other methods, even though the Flaxman method was developed specifically for conditions in the western United States. Like the PSIAC method, it has no direct term reflecting watershed area. When the additional parameter is used to reflect the 2-yr frequency annual peak discharge, the results improve. The results of the prediction also improved dramatically when the actual flood series was used to estimate the parameter rather than using the simple estimate of precipitation and converting that value to a peak flow.

The Dendy/Bolton method overestimated sediment yield in all cases. The predictions might have improved slightly if actual runoff data had been used to replace the relationship of eq. 3. Thus, an improvement like that obtained with the Flaxman (1974) method might be expected.

The Renard method also overestimated the sediment yield in all but one case. Predictions might improve if the technique were used to simulate the sediment yield using channel characteristics and observed runoff for each individual watershed, rather than the average conditions with which the model was calibrated, and then simplified to the form shown in eq. 7. For example, some of the ponds had grass swales; in other locations, the channels are more rectangular and contain large amounts of sand which more nearly duplicate the conditions of the large watersheds. Thus, sediment accumulation in tanks with sand channels (208, 214, 216, and 223) would be expected to be closer to the predicted, as observed on all but tank 208. If such a scheme were used, it would be somewhat analogous in detail to the SWRRB/MUSLE technique.

The SWRRB/MUSLE method is considerably more complex and, thus, requires more input data than the other methods. However, its results were not significantly closer to the measured values than those of the other methods. Intuitively, we think the problem is not with the MUSLE part of the scheme but, rather, is associated with the inadequacy of the SCS curve number hydrology option used to produce runoff peaks and volumes commensurate with the observed values. Previous work by Simanton et al. (1973), Hawkins (1978a and 1978b), and others, has illustrated problems with using the CN precipitation/runoff relationship.

SENSITIVITY OF PREDICTED SEDIMENT YIELD TO CURVE NUMBER IN SWRRB/MUSLE

Since most summer runoff events in the Basin and Range Province occur under antecedent moisture condition (AMC) I, SWRRB was modified for the purpose of this paper to accept CN I directly as input instead of requiring calculations from CN II as the program was originally written. Input values for CN I were calculated from the SCS curve number equation using observed rainfall-runoff data for Walnut Gulch and solving for the optimum CN. To test the sensitivity of predicted sediment yield to curve number, the calculated CN values were varied $\pm$ 2 and + 10. The results are similar for each of the tanks studied.

As shown in Fig. 1, predicted sediment yield (with the exception of CN + 10) changes very little, with variations within the range of values of curve number typical for Walnut Gulch.

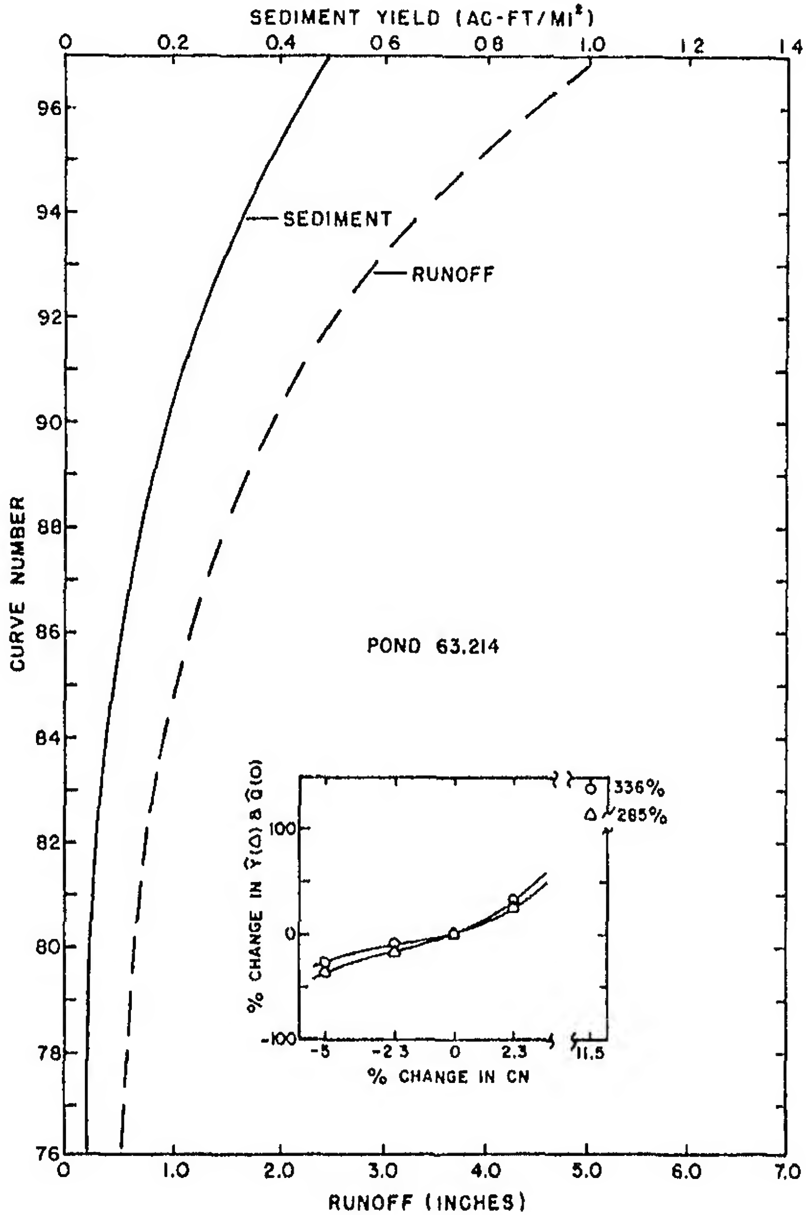

Figure 1.--Sensitivity of runoff and sediment yield to varying curve number.

No sensitivity analysis of sediment yield to the USLE factors (KLSCP) in MUSLE was done since these factors are linearly related to sediment yield and, unlike the runoff factor, remain constant for the period of simulation. However, there is a high potential for error inherent in MUSLE due to the difficulty of evaluating factors like "C" and "K" for a semiarid rangeland environment.

The simulated versus observed sediment yield data for the nine small watersheds on Walnut Gulch are summarized in Fig. 2. Also shown are regression lines and coefficients of determination, r^2, for each method. The results are discouraging. They illustrate that considerable improvement is needed in the technology of estimating sediment yield. The low r^2 values, in most instances, result from one data point. For example, the r^2 for the MUSLE prediction improves to 0.55 by eliminating the prediction on pond 213. From a statistical viewpoint, the PSIAC method is the best of the six methods.

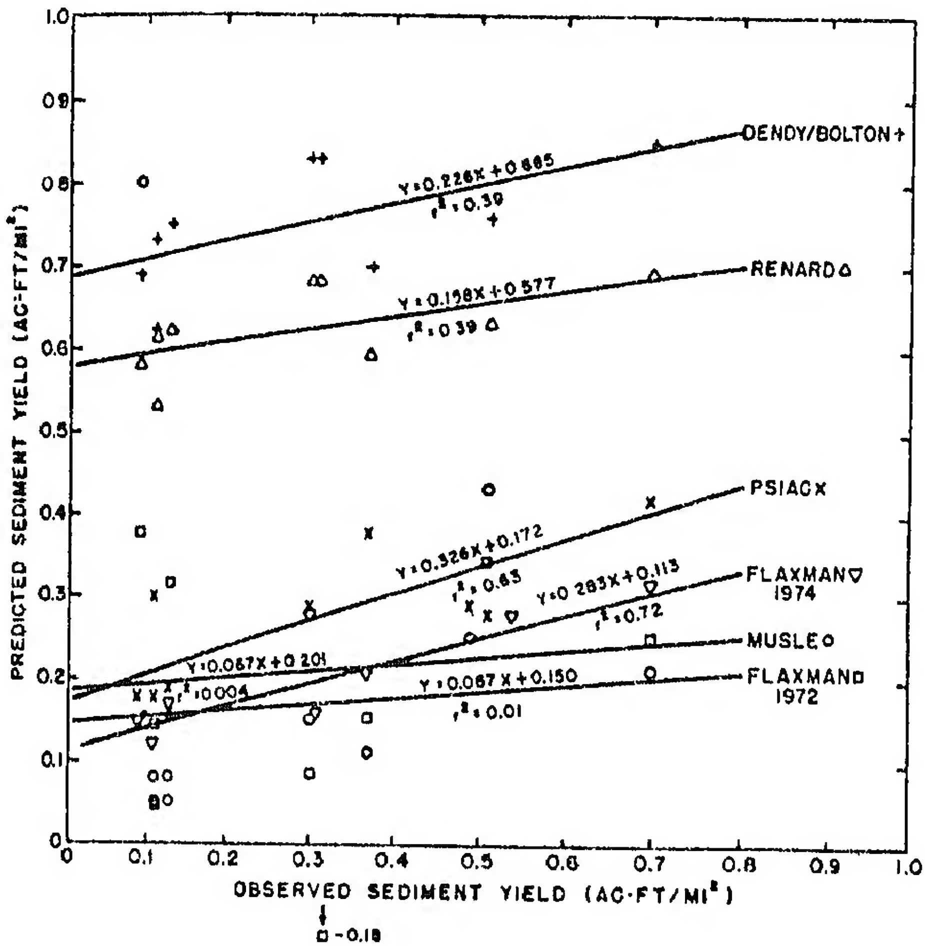

Figure 2.--Correlations of observed and predicted sediment yield for the six prediction relationships tested.

REPRESENTATIVENESS OF SHORT RECORDS

When relatively short records are used in developing and testing prediction schemes, such as the sediment yield methods tested herein, one immediately onders whether the sample includes all extremes of the climate and if the ort-term mean value and standard deviation are the same as that for a longerm record. In the southwestern United States, the coefficient of variation f annual precipitation is maximum for any of the locations considered by Hershield (1962). Knisel et al. (1979) investigated methods to evaluate the length

of record necessary for water resource data collection. One of the methods investigated involved a cumulative surplus/deficit analysis of the annual precipitation. The surplus/deficit analysis depicts trends that may otherwise be obscure and is obtained by cumulating departures from a long-term mean.

Figure 3 illustrates the long-term annual rainfall amounts and cumulative surplus/deficit from the 13.66-in mean for the raingage at Tombstone, within the Walnut Gulch Experimental Watershed. In only 1 yr was rainfall above the long-term mean for the period used in the sediment yield evaluation. The negative slope to the surplus/deficit graph for the period since 1957 illustrates the general dry trend during the study period. Since 1957, rainfall has been about 8% below normal. Thus, the vegetation cover would be expected to be poorer than that for a wetter period, and runoff which transports the eroded material might be less than the long-term mean.

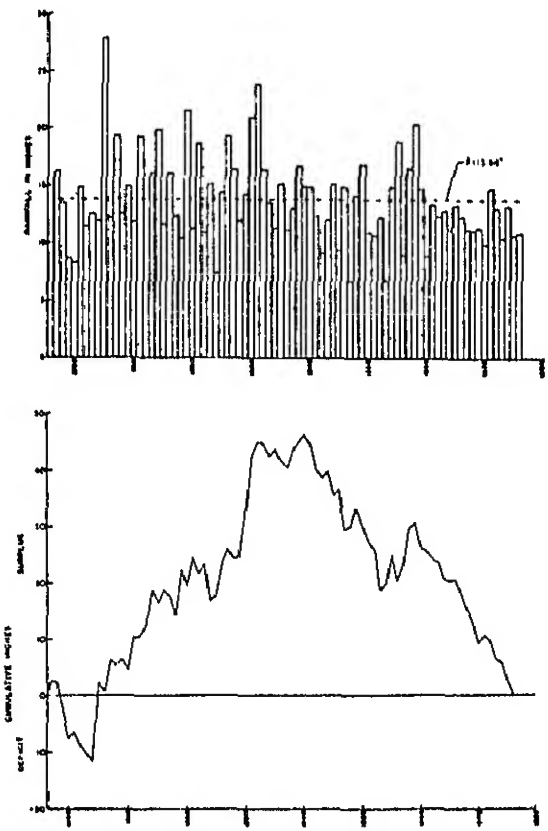

Figure 3.--Annual precipitati..n and cumulative surplus/deficit for Tombstone, Arizona (Knisel et al., 11).

The importance of an unusual storm in affecting long-term sediment yield trends has been well documented. Thus, it is entirely possible that some of the observed yields are low because of low precipitation/runoff or even the absence of more infrequent events. Stock tanks 214, 215, and 216, on the other hand, have had some large storms during their short records (Osborn and Renard, 1969), which may partly explain why the observed yields for these ponds are larger and somewhat closer for the predicted values.

CONCLUSIONS

1. Predicting sediment yield in the western United States, despite recent developments in water resource models, is difficult and often subjective. The wide variations in watershed characteristics over short distances add to the problem.

2. Of the methods investigated, the PSIAC method appears to give the best results for the amount of work required to make the estimate. The SWRRB/MUSLE method also gave good results (except for pond 213), but the amount of work required for the hydrologic portion of the model is considerable. Certainly, it is potentially a powerful tool for evaluating management practices.

3. Only the PSIAC and the SWRRB/MUSLE methods allow the use of factors (parameters) that reflect management practices. The Renard method also could be used to reflect management practices if the stochastic runoff model and the sediment transport relationship were used directly rather than as simplified with eq. 7.

4. The Flaxman method, as modified in 1974, illustrates some of the improvement which can be obtained by inclusion of an additional term to reflect the 2-yr frequency peak flow. Estimating the peak flow with actual records also improved the correlation between observed and predicted sediment yields over converting the 2-yr precipitation frequency estimate using a rainfall-runoff relationship.

5. The methods tested generally underpredicted sediment yield. The underprediction may, in part, be associated with the questionable representativeness of the climatic sample for the period of observation. Records at all but three of the watersheds were known to be lower than normal in precipitation/runoff, and thus, those results are undoubtedly below what might be considered the mean annual sediment yield.

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PREDICTING SEDIMENT YIELDS FROM SAGEBRUSH RANGELANDS

Clifton W. Johnson, SEA research hydraulic engineer
and Karl A. Gebhardt, BLM hydrologist[1/]

INTRODUCTION

Soil erosion and sediment yield are major concerns to landowners and managers responsible for maintaining rangeland productivity and conservation of land resources. Since the Bureau of Land Management (BLM), U.S. Department of Interior, is responsible for administration of about 72 million ha of land in the conterminous United States, Clawson and Held (1957), the department must address the complex environmental impacts of grazing, land and energy development, and alternative land uses. The legal requirements of Environmental Impact Statements (EIS) on areas of proposed development have shown the need for accurate and quantitative erosion and sediment yield methods for predicting results of land disturbance and management.

Comparative analysis is a common technique in EIS preparation, because it shows the effects of alternative action in relation to present conditions or some recognized standard. Generally, there is a lack of on-site field data and, because of the large expense required for information collection, Richerson and Johnston (1975), appropriate methods and data must often be extrapolated to the area under consideration. This study shows an application of the Pacific Southwest Inter-Agency Committee (1968) sediment yield prediction procedure (PSIAC) compared with measured yields from sagebrush rangeland areas in southwest Idaho.

Application of the PSIAC procedure was similar to studies reported by Shown (1970), Liefeste (1978), Clark (1980), and Renard (1980) with some changes, to utilize available sagebrush rangeland watershed data. Although the procedure was developed for the Pacific Southwest, it includes factors important in estimating sediment yield with a wide variety of conditions. Objectives of this study were to test the sensitivity of the PSIAC procedure in response to changes in grazing and vegetative cover, to compare measured and predicted sediment yields, and to show how the method can be used in predicting the effects of rangeland management practices on sediment yield.

1/ Northwest Watershed Research Center, USDA-SEA-AR, Suite 116, 1175 South Orchard, Boise, Idaho 83705 and Idaho State Office, USDI-BLM, 550 W. Fort St., Room 386, Boise, Idaho 83724. In cooperation with the Agricultural Experiment Station, University of Idaho, Moscow, Idaho 83843.

PROCEDURE

Sediment yields were computed by a modified PSIAC procedure using the equation

$$Sy = 0.253e^{0.036 \text{ Rating}} \quad [1]$$

where, SY is the sediment yield in t/ha (metric tonnes/ha), assuming a sediment volume-weight of 1,360 kg/m^3, e is the base of natural logarithms, and Rating is the sum of PSIAC factors (see Figure 1). Equation [1] was derived from Leifeste's (1978) data adjusted to eliminate minus values; thus, changing the rating but not the procedure. The relationship shown in Figure 1 is highly variable and poorly defined below about 0.4 t/ha sediment yield. The PSIAC Rating values were defined by the equation

$$\text{Rating} = Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6 + Y_7 + Y_8 + Y_9 \quad [2]$$

where, Y_1 is the surface geology factor, Y_2 is the soils factor, Y_3 is the climate factor, Y_4 is the runoff factor, Y_5 is the topography factor, Y_6 is the ground cover factor, Y_7 is the land use factor, Y_8 is the upland erosion factor, and Y_9 is the channel erosion and sediment transport factor. These factors and the independent variables used to determine the relationships are listed in Table 1.

WATERSHEDS AND STUDY SITES

Sagebrush rangeland hydrologic and related research have been conducted on the Reynolds Creek Experimental Watershed in southwest Idaho since 1960, obins et al. (1965). Watersheds, vegetation and grazing study sites, and epresentative cover transect locations are shown in Figure 2. Watershed :haracteristics for the three watersheds selected for this study are listed in Table 2. Average annual precipitation, 1962 through 1978, ranged from 250 mm in the lower valley (1190 m elevation) to 1070 mm at an elevation of 2090 m. Precipitation at the Reynolds weather station (1200 m elevation) ranged from 143 mm in 1966, a drought year, to 445 mm in 1965, a wet year. Runoff ranged from zero in some years at the lowest elevations with less than 250 mm precipitation, to 885 mm in the 1965 water year at Reynolds Mountain station, with 1676 mm precipitation. Measured sediment yields ranged from 0.02 to 3.4 t/ha/yr and were extremely variable from year to year at all stations and depended mainly on runoff conditions, Johnson and Hanson (1976) and Johnson and Smith (1978).

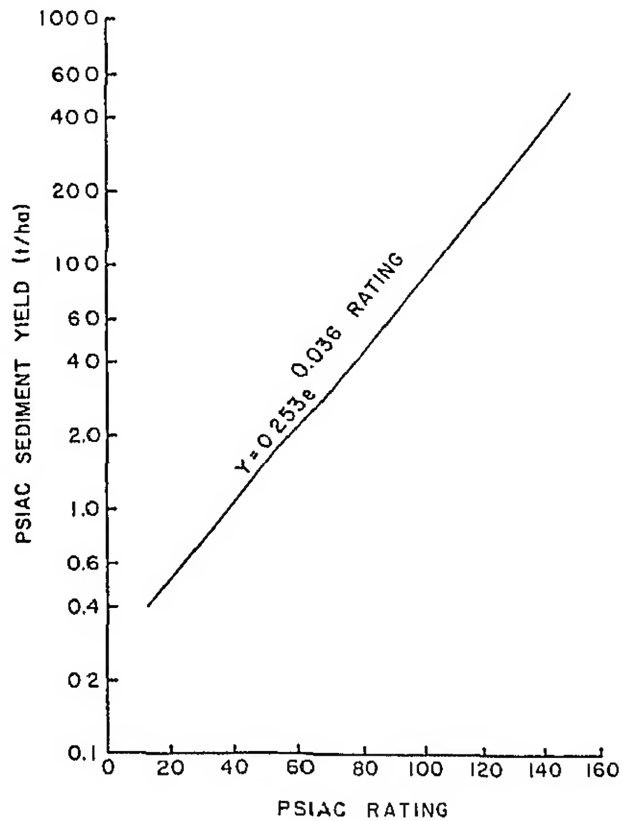

Figure 1. The relationship between PSIAC rating and sediment yield derived from Leifeste's (1978) data.

RESULTS AND DISCUSSION

Maximum, minimum, and area-weighted mean PSIAC factor values for the three watersheds are summarized in Table 3 and show a wide range for most factors. The greatest predicted mean sediment yield, 2.06 t/ha/yr, Salmon Creek, was accounted for by less ground cover, more intensive land use, greater slope, and more visible evidence of upland and channel erosion. Upland and channel erosion estimates were made by the BLM Soil Surface Factor (SSF) rating system, based on ocular field estimates of soil movement, surface litter, surface rock, pedestalling, flow patterns, rills, and gullies, described in BLM Manual 7317. Predicted watershed sediment yields were within about 15 percent of measured yields, Table 3. Considering the wide year-to-year variation in measured sediment yields and only 8 to 10 years of sediment records, the predicted yields compare favorably with measured yields.

Percent bare ground, percent canopy cover, and SSF were determined on eight ungrazed and eight moderately to heavily grazed areas of the Reynolds Creek Watershed from 1972 through 1979 to evaluate the effects of grazing on PSIAC sediment yield. The relationships between grazed and ungrazed areas

Table 1.--Descriptions of PSIAC factors and relationships used in Equation [2].

PSIAC Factor	Equation and Description
Surface geology	$Y_1 = X_1$, where X_1 is a geologic erosion index based on rock type, hardness, fracturing, and weathering from geologic reports (hard massive rock has an index of one and marine shale, mudstone, or siltstone has an index of 10).
Soils	$Y_2 = 16.67X_2$, where X_2 is the Universal Soil Loss Equation, USLE, soil erodibility factor value determined by procedures of Wischmeier and Smith (1978).
Climate	$Y_3 = 0.2X_3$, where X_3 is 2-year, 6-hour precipitation amount in mm determined from weather records.
Runoff	$Y_4 = 0.2X_4$, where X_4 is the sum of yearly runoff volume in mm times 0.03 and of yearly peak streamflow in $m^3/sec/km^2$ times 50.
Topography	$Y_5 = 0.33X_5$, where X_5 is slope steepness in percent.
Ground cover	$Y_6 = 0.2X_6$, where X_6 is bare ground in percent.
Land use	$Y_7 = 20-0.2X_7$, where X_7 is canopy cover in percent.
Upland erosion	$Y_8 = 0.25X_8$, where X_8 is the Soil Surface Factor, SSF, determined by procedures described in Bureau of Land Management, BLM, Manual 7317.
Channel erosion	$Y_9 = 1.67X_9$, where X_9 is the SSF gully rating associated with X_8.

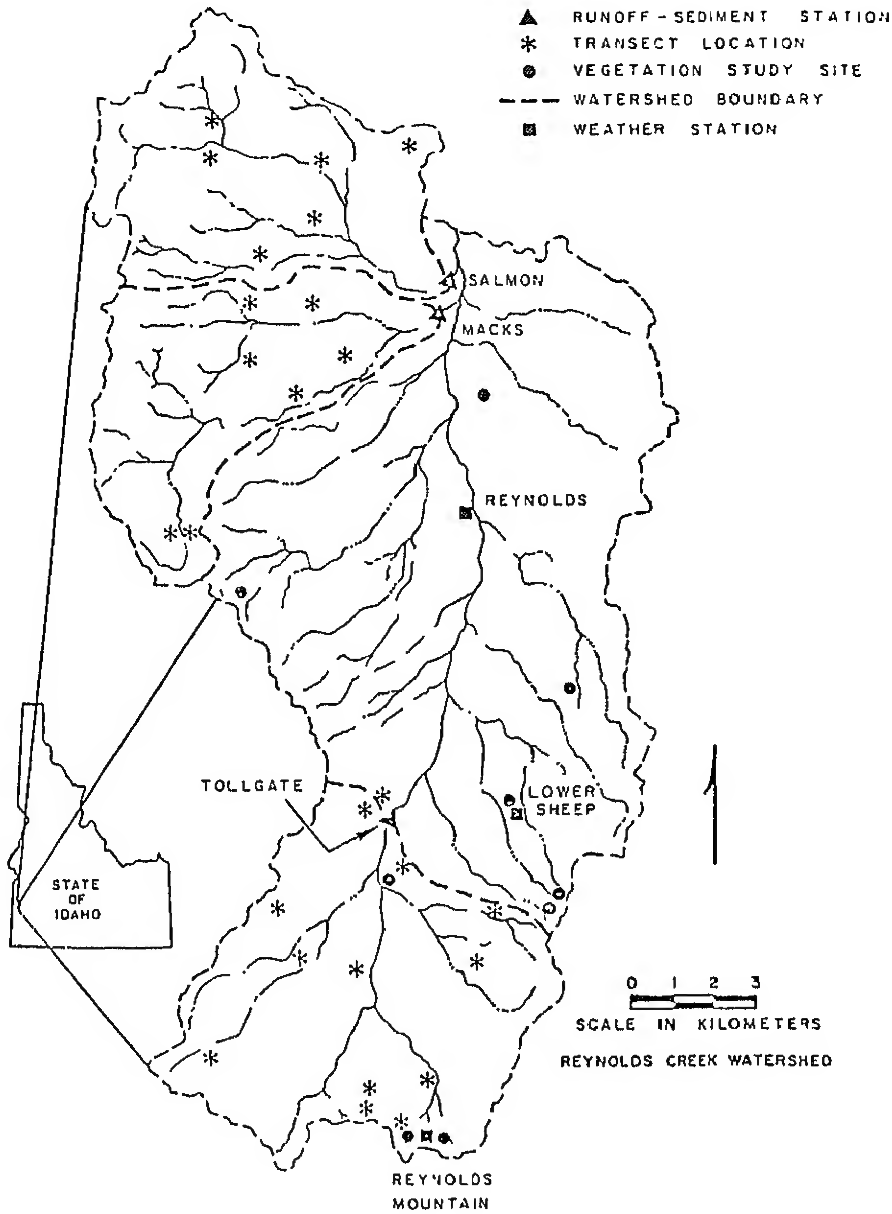

Figure 2. Locations of hydrologic instrumentation, vegetation study sites, and cover transects, Reynolds Creek Experimental Watershed.

Table 2.--Watershed and vegetation study site descriptions, Reynolds Creek Experimental Watershed.

Watershed	Drainage area	Elevation range	Precipitation range	Runoff range	Measured sediment yield
	km^2	m	mm	mm	t/ha/yr
Salmon Creek	36.4	1120-1920	300-560	10-280	1.90
Macks Creek	31.8	1140-1890	300-530	10-270	1.57
Reynolds Creek above Tollgate	54.5	1400-2230	470-1320	12-760	1.50

Study site	Elevation	Precipitation	Grazed bare ground	Grazed total canopy	Grazed SSF
	m	mm	%	%	
Flats	1190	250	58	41	19
Nancy	1400	350	38	34	27
Whiskey Hill	1650	580	30	67	23
Lower Sheep	1650	360	25	45	24
Upper Sheep, South Face	1860	500	44	42	32
Upper Sheep, North Face	1860	500	16	71	8
Reynolds Mountain, West	2090	1020	19	47	17
Reynolds Mountain, East	2090	1020	22	80	7
Nettleton	1500	480	32	52	17

Table 3.--Summary of PSIAC factor values for watersheds on Reynolds Creek.

	Watershed								
	Salmon Creek			Macks Creek			Reynolds Tollgate		
	Max.	Min.	Mean[1/]	Max.	Min.	Mean[1/]	Max.	Min.	Mean[1/]
Surface geology	7.0	3.0	4.2	7.0	3.0	4.8	6.0	4.0	5.2
Soils	5.3	4.3	4.6	5.0	3.5	4.5	4.7	1.8	4.0
Climate	6.0	4.6	5.2	6.4	4.6	5.4	8.1	4.8	6.6
Runoff	4.1	1.2	2.2	3.2	1.2	2.1	6.0	0.9	2.8
Slope	16.6	2.5	7.9	15.0	2.5	7.6	16.0	3.0	7.4
Ground cover	6.4	2.4	4.7	4.4	2.7	3.4	6.0	2.0	3.4
Land use	14.0	7.0	10.2	13.0	7.0	8.9	12.0	3.0	6.3
Upland erosion	11.5	8.0	10.4	11.6	4.0	6.2	10.0	2.5	5.6
Channel erosion	14.0	4.0	8.9	11.0	2.0	5.4	6.0	2.0	3.5
Rating	65.5	53.2	58.3	58.7	44.7	48.3	63.8	39.4	44.8
Predicted sediment yield, t/ha/yr	2.67	1.72	2.06	2.09	1.26	1.44	2.53	1.03	1.29
Measured sediment yield, t/ha/yr			1.90			1.57			1.50

1/ Area weighted means.

for bare ground, canopy cover, and SSF are shown in Figures 3, 4, and 5, respectively. The differences in computed sediment yield were determined by changing PSIAC ground cover, land use, and upland erosion factors, as appropriate, from Figures 3, 4, and 5. Results (Table 4) show that excluding cattle grazing for 8 years reduced predicted sediment yield about 0.2 t/ha/yr.

The effects of extremely heavy cattle grazing, about 90 percent forage utilization, on PSIAC sediment yield were estimated at one of the vegetation study sites, Figure 2. Average 1972 through 1978 data at the site showed 32 percent bare ground, 52 percent canopy cover, and an SSF of 17 on the grazed area and 17 percent bare ground, 65 percent canopy cover, and an SSF of 9 on the ungrazed area. At this site, differences in ground cover on grazed and ungrazed areas were highly significant ($P < .01$), Johnson et al. (1980). The resulting estimated PSIAC sediment yield was 1.34 t/ha/yr on the heavily grazed areas and 1.02 t/ha/yr on the ungrazed areas. The greater percent bare ground on the grazed area was the major cause of the 30 percent increase in PSIAC predicted sediment yield.

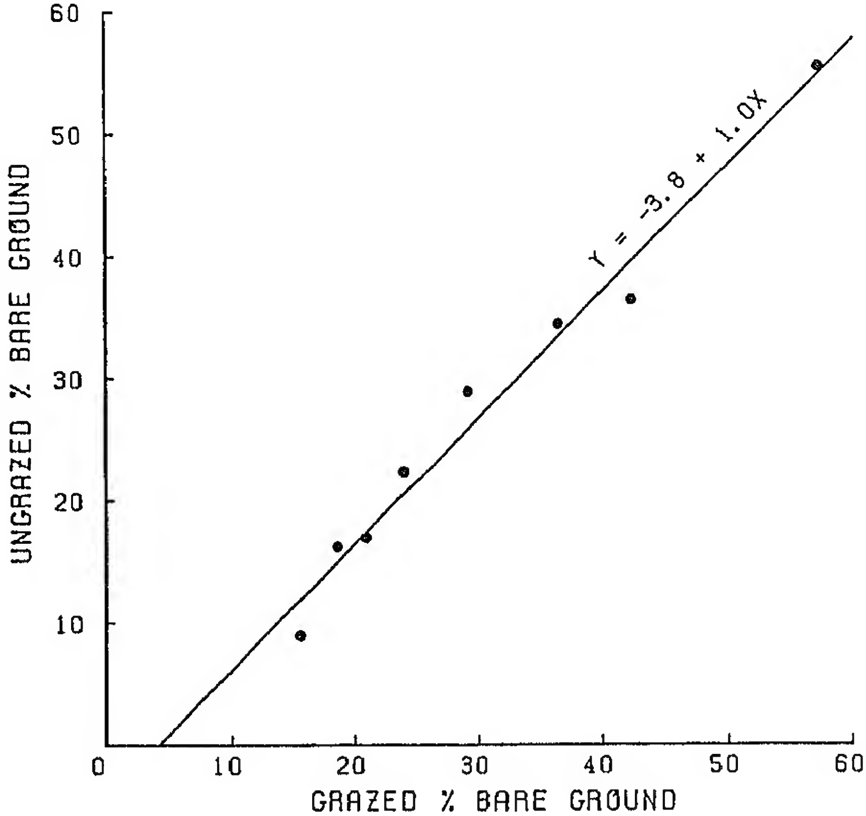

Figure 3. The relationship between percent bare ground on grazed and ungrazed study sites.

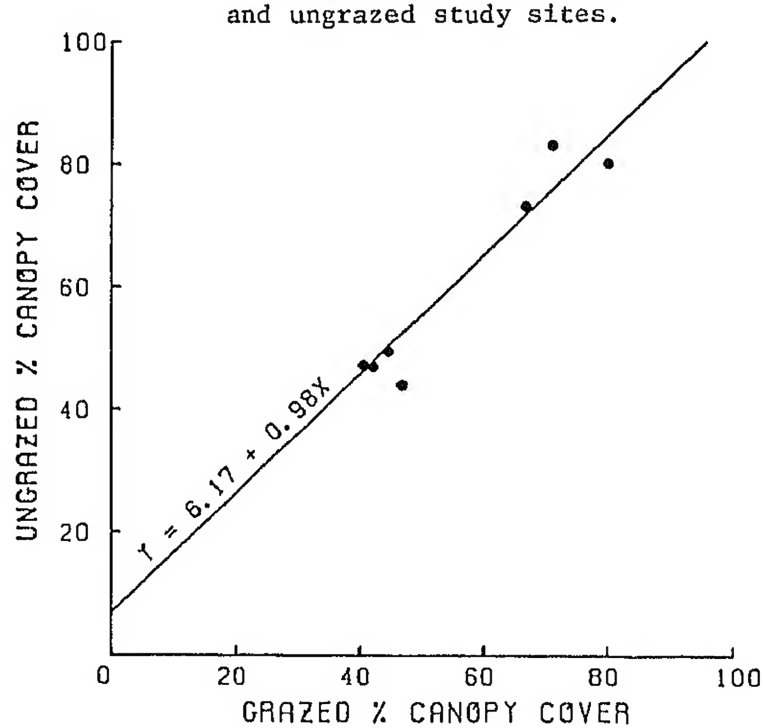

Figure 4. The relationship between percent canopy cover on grazed and ungrazed study sites.

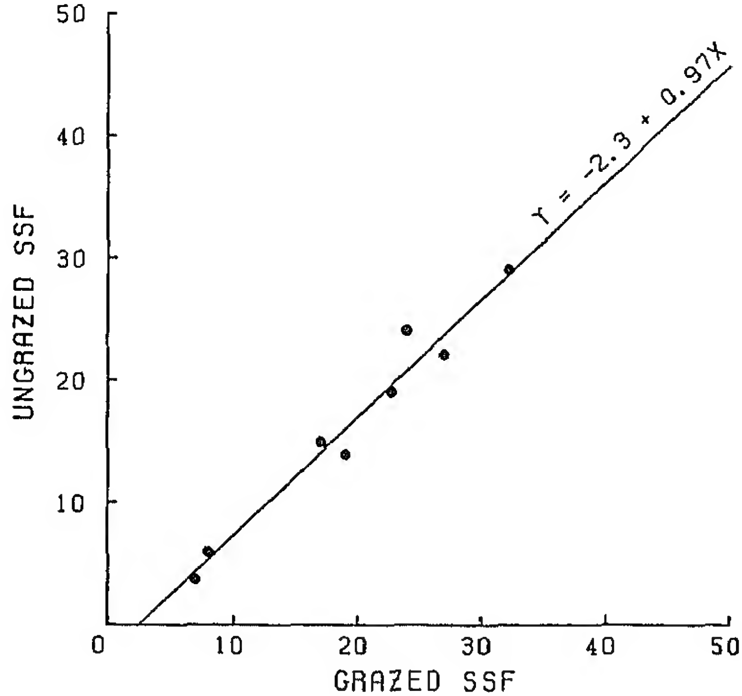

Figure 5. The relationship between Soil Surface Factor (SSF) values on grazed and ungrazed study sites.

Table 4.--Comparison of PSIAC factors and sediment yield based on data from ungrazed and grazed study sites.

	Watershed					
	Salmon Creek		Macks Creek		Reynolds Tollgate	
	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed
Ground cover	3.95	4.71	2.59	3.35	2.64	3.40
Land use	9.13	10.17	7.84	5.85	5.34	6.30
Upland erosion	9.47	10.36	5.41	6.17	4.86	5.60
Predicted sediment yield, t/ha/yr	1.82	2.06	1.25	1.44	1.17	1.29

Sagebrush was cut and removed from three ungrazed sites and was sprayed with 2,4-D or 2,4-T at four ungrazed sites to improve forage production and to study vegetative cover changes, 1972-1975. Results from this study, Schumaker and Hanson (1977), were analyzed by the PSIAC procedure to estimate the effects of the sagebrush eradication treatments on sediment yield (Table 5). Generally, predicted sediment yields on the ungrazed areas without sagebrush treatment were less than on areas where sagebrush was removed or killed by spraying. PSIAC estimates showed only about 0.1 t/ha/yr increase in sediment yield where sagebrush was cut and removed.

Table 5.--Estimated PSIAC sediment yield, t/ha/yr, at sagebrush treatment sites, Reynolds Creek Experimental Watershed, 1972-1975.

	Site			
Treatment	Nancy	Whiskey Hill	Upper Sheep, N.F.	Reynolds Mt. E.
Ungrazed	1.37	1.14	0.90	0.82
Grazed	1.59	1.23	1.03	1.02
Sprayed	1.31	1.15	0.98	1.05
Cut	1.41	--	1.06	0.94

SUMMARY AND CONCLUSIONS

The PSIAC sediment yield prediction procedure used in this study needs wider application and verification; however, predicted yields in this study were within 15 percent of measured watershed sediment yields and provide a method for comparing and predicting effects of different site conditions and management changes. The equations developed in this study to evaluate individual PSIAC factors are an improvement over subjective narrative method used in the original procedure.

Average yearly predicted sediment yields from three Reynolds Creek watersheds by the PSIAC procedure ranged from 1.3 to 2.1 t/ha/yr. Predicted yields on watershed subareas ranged from 1.0 to 2.7 t/ha/yr in response to PSIAC factor values.

Moderate to heavy cattle grazing increased PSIAC estimated sediment yield about 0.2 t/ha/yr, based on differences in vegetative cover on grazed areas and areas that had been ungrazed about 8 years. Extremely heavy cattle grazing increased PSIAC estimated sediment yield 0.32 t/ha/yr. PSIAC estimated

sediment yield was only increased about 0.1 t/ha/yr where sagebrush was cut and removed. Sagebrush eradication by spraying had less effect on sediment yield than moderate-to-heavy grazing.

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TESTING THE MODIFIED UNIVERSAL SOIL LOSS EQUATION

J. R. Williams, SEA hydraulic engineer

INTRODUCTION

The Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) was developed by replacing the rainfall energy factor of the USLE (Wischmeier and Smith, 1978) with a runoff energy factor. The MUSLE runoff energy factor is a function of the product of the runoff volume and the peak runoff rate for an individual storm. Since its introduction, the runoff energy factor has been used in several other erosion/sedimentation models (Onstad and Foster, 1975; Foster et al., 1977; Foster et al., 1980). Advantages of replacing the rainfall energy factor with the runoff factor include: (1) Increased accuracy because runoff generally explains more variation in sediment yield than rainfall does; (2) Eliminates the need for delivery ratios because the runoff factor represents energy used in transporting as well as detaching sediment; and (3) Applies to individual storms (an important attribute particularly in simulating water quality).

The MUSLE was developed using data from 18 small watersheds with areas ranging from 1 to 1773 ha and slopes ranging from 0.94 to 5.9 percent. Sixteen of the watersheds were located at Riesel, Texas, and two were located at Hastings, Nebraska. The data set included 778 individual runoff events. The MUSLE is

$$Y = 11.8\ (V\ q_p)^{0.56}\ (K)(C)(P)(LS)$$

where Y is the sediment yield for an individual storm in t, V is the volume of runoff for the storm in m^3, q_p is the peak runoff rate in m^3/s, K is the soil erodibility factor, C is the crop management factor, P is the erosion control practice factor, and LS is the slope length and steepness factor. Since its development, MUSLE has been applied and tested at many locations (Williams and Berndt, 1977). The purpose here is to present test results from a large number of watersheds with widely varying characteristics and climates.

TEST WATERSHEDS

A group of 59 SEA-AR watersheds (including the 18 used in the development) that were used to test MUSLE are listed in Table 1. These watersheds represent a wide variety of conditions generally encountered in predicting sediment yield

U.S.--areas range from 1 ha to 234 km^2; slopes range from 0.2 to 28 percent; average annual rainfall ranges from 480 to 1270 mm; and land use ranges from 100 percent cropland to 100 percent pasture with some forested areas. These tests were conducted using measured runoff volumes and peak rates from 2976 individual events.

Although tests using measured runoff volumes and peak rates are essential in determining MUSLE's prediction accuracy, measured runoff is almost never available in practice. Thus, to compare MUSLE's accuracy with that of the USLE, one must link MUSLE with a suitable runoff simulation model. Various runoff models have been used for this purpose (Smith et al., 1977; Simons et al., 1977; Fogel et al., 1977; Mills, 1971; Williams and Berndt, 1977). Recently, Williams and Nicks (1981) expanded the CREAMS (Knisel, 1980) daily rainfall hydrology model for application to complex basins. The MUSLE was linked to the new hydrology model to form a simulator for water resources on rural basins (SWRRB). The SWRRB model was applied to the watersheds shown in Table 2 for test purposes.

Sediment yield data from 39 of the 43 watersheds shown in Table 2 was collected by the Soil Conservation Service using reservoir surveys (the watersheds drain into SCS P.L. 566 reservoirs). Sediment data from four watersheds (Big Sandy Creek, Clear Creek, Little Elm Creek, and Pin Oak Creek) was obtained by streamflow sampling. Land use and soils information were provided by SCS geologists. Topographic information was taken from U.S. Geological Survey topographic maps.

Like the previous test watersheds, these watersheds provide a good variety of conditions for testing the general applicability of MUSLE--areas range from 0.6 to 513 km^2; slopes range from 2 to 36 percent; average annual rainfall ranges from 200 to 1605 mm; and land use ranges from 77 percent cropland to 100 percent pasture and range and to 100 percent forest and woods.

TEST RESULTS

Results of tests using measured runoff from the watersheds shown in Table 1 are presented in Table 3. Generally, MUSLE performed satisfactorily--R^2 (obtained by comparing measured and predicted individual storm sediment yields) was 0.8 or greater for most of the watersheds. Only five watersheds had R^2 values less than 0.5 Four of these were small flat (slopes <0.5%) watersheds at Chickasha, Oklahoma, cropped in continuous cotton. Two of these watersheds, C-3 and C-4, received supplemental irrigation. These results indicate that the LS factor may need refinement for flat slope applications of MUSLE.

Another attribute probably more important than R^2 is a models ability to simulate sediment yield frequency distributions that are similar to those of measured data. Two indicators of close agreement between frequency distributions are shown in Table 3 (average annual sediment yield and the standard deviations of individual events). Both of these statistics indicate that MUSLE generally simulated sediment yields quite realistically for the test watersheds.

In previous tests by the author and others, there has been some evidence that MUSLE tends to overpredict small storms and underpredict large ones. Some of the test watersheds shown in Table 3 support the previous evidence and some do not. Thirty-eight of the regression slopes (observed yields-dependent variable; simulated yields-independent variable) are greater than one and 27 are less than one. Of course, a regression slope greater than one indicates that large storms are underpredicted. Of the 38 regression slopes greater than one, only 11 are greater than 1.25. Fortunately, these 11 high regression slopes were produced on watersheds with relatively low sediment yields. Underpredicting large events on high sediment yielding watersheds would increase the magnitude of the error considerably.

Although these tests do not confirm that MUSLE underpredicts large storm yields, the evidence indicates that the runoff energy factor and the P factor should be examined carefully in search of deficiencies. The form of the energy factor or the values of its parameters may need refinement. Also, the P factor should be modified to reflect the performance of conservation practices as storm size varies. A conservation practice like terraces will usually reduce sediment yield considerably for storms up to the design storm size. However, larger storms may overtop the terraces and eliminate their effectiveness completely.

Test results for the SCS and USGS watersheds described in Table 2 are given in Table 4. Since data was collected by reservoir survey for most of these watersheds, only the accumulated sediment yield is available for comparison. Runoff and sediment yield from sheet and rill erosion were simulated for the period of record using SWRRB. Gully sediment yield was estimated by SCS geologists by applying delivery ratios to annual gully erosion estimates for some of the watersheds (blanks in Table 4 means that the estimates are not yet available). As shown in Table 4, the simulated average annual runoff is equal to the measured amounts for the first 22 watersheds. This was accomplished using parameter optimization to minimize the difference between measured and predicted average annual runoff. Later, the SWRRB model was modified to better describe hydrologic processes using readily available physically based data. Thus, the need to calibrate by optimizing parameters was eliminated. Simulations for the last 21 watersheds shown in Table 4 were performed without calibration.

The predicted sediment yields shown in Table 4 are the sums of the MUSLE simulated sediment yields from sheet and rill erosion and the estimated gully erosion sediment yields. Although the gully erosion estimates are not yet available for several of the watersheds, the preliminary results are generally satisfactory.

SUMMARY AND CONCLUSIONS

The MUSLE was tested with data from 102 watersheds located throughout the U.S. These watersheds provided a wide range in watershed and climatic characteristics and management strategies. In tests using measured runoff data, MUSLE generally gave satisfactory results, but two possible deficiencies were discovered: (1) the LS factor may not be adequate for flat slope watersheds; and (2) there may be a tendency for MUSLE to overpredict small storms and underpredict large ones--the runoff energy and P factors need attention.

MUSLE was linked with an expanded version of the CREAMS daily rainfall hydrology model to provide estimates of the runoff factor. The new hydrology-sedimentation model called SWRRB shows promising results although some of the tests are not complete.

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TABLE 1. GENERAL INFORMATION ABOUT SEA-AR WATERSHEDS USED IN TESTING MUSLE WITH MEASURED RUNOFF

WATERSHED	LOCATION	ST.	PERIOD OF RECORD	DRAINAGE AREA HA	******** LAND USE % CROP LAND	PASTURE RANGE	******* FOREST WOODS	AVERAGE SLOPE %
A	RIESEL	TX	1939-43	16.99	79.50	20.50	0.00	1.57
D	RIESEL	TX	1939-43	448.07	71.00	29.00	0.00	2.61
D	RIESEL	TX	1960-70	448.07	31.00	69.00	0.00	2.61
G	RIESEL	TX	1960-70	1771.56	23.00	77.00	0.00	2.25
J	RIESEL	TX	1939-43	2372.44	74.80	25.20	0.00	2.14
SW-2	RIESEL	TX	1939-43	1.09	100.00	0.00	0.00	1.90
SW-3	RIESEL	TX	1939-43	1.25	100.00	0.00	0.00	1.90
SW-5	RIESEL	TX	1939-43	1.25	100.00	0.00	0.00	3.30
SW-6	RIESEL	TX	1939-43	1.23	100.00	0.00	0.00	3.20
SW-7	RIESEL	TX	1939-43	1.27	100.00	0.00	0.00	1.70
SW-11	RIESEL	TX	1939-43	1.31	100.00	0.00	0.00	0.94
SW-12	RIESEL	TX	1939-43	1.20	100.00	0.00	0.00	3.80
SW-13	RIESEL	TX	1939-43	1.29	100.00	0.00	0.00	3.10
SW-16	RIESEL	TX	1939-43	1.28	100.00	0.00	0.00	2.59
SW-17	RIESEL	TX	1939-43	1.21	100.00	0.00	0.00	1.93
SW-18	RIESEL	TX	1939-43	1.23	100.00	0.00	0.00	1.14
Y	RIESEL	TX	1939-43	125.10	76.50	23.50	0.00	2.57
Y	RIESEL	TX	1960-70	125.10	51.00	49.00	0.00	2.57
Y-2	RIESEL	TX	1944-47	53.35	73.20	26.80	0.00	2.86
Y-2	RIESEL	TX	1960-70	53.35	66.00	34.00	0.00	2.86
Y-6	RIESEL	TX	1939-43	6.47	100.00	0.00	0.00	3.21
Y-6	RIESEL	TX	1962-72	6.60	93.30	6.70	0.00	3.21
Y-8	RIESEL	TX	1969-72	8.42	94.70	5.30	0.00	2.24
Y-10	RIESEL	TX	1939-41	8.50	100.00	0.00	0.00	1.88
Y-10	RIESEL	TX	1967-72	7.54	92.70	7.30	0.00	1.98
Y-13	RIESEL	TX	1969-72	4.58	95.60	4.40	0.00	2.30
Y-14	RIESEL	TX	1969-72	2.27	96.40	3.60	0.00	1.38
W-1	RIESEL	TX	1939-47	71.22	84.50	15.50	0.00	2.30
W-1	RIESEL	TX	1960-70	70.45	69.00	31.00	0.00	2.30
W-2	RIESEL	TX	1939-47	52.58	67.00	33.00	0.00	2.45
W-6	RIESEL	TX	1960-69	17.12	75.30	24.70	0.00	2.03
W-8	RIESEL	TX	1939-41	16.34	79.20	20.80	0.00	2.28
W-10	RIESEL	TX	1940-43	7.98	100.00	0.00	0.00	2.07
W-12	RIESEL	TX	1970-72	4.01	97.00	3.00	0.00	2.01
W-13	RIESEL	TX	1970-72	4.58	96.50	3.50	0.00	1.07
W-3	HASTINGS	NE	1957-67	194.77	48.00	52.00	0.00	5.40
W-5	HASTINGS	NE	1957-67	166.28	54.00	46.00	0.00	5.90
68.001	BOISE	ID	1967-74	23361.80	3.00	95.00	2.00	22.70
68.004	BOISE	ID	1967-74	5439.00	0.00	99.00	1.00	23.30
68.002	BOISE	ID	1968-74	3626.00	1.00	99.00	0.00	27.60
68.003	BOISE	ID	1968-74	3185.79	2.00	98.00	0.00	25.70
5140	CHICKASHA	OK	1969-72	2930.67	0.00	100.00	0.00	8.50
5141	CHICKASHA	OK	1969-72	1444.65	0.00	100.00	0.00	8.70
5142	CHICKASHA	OK	1969-72	145.04	0.00	100.00	0.00	8.20
5143	CHICKASHA	OK	1969-72	196.84	0.00	100.00	0.00	7.80
5144	CHICKASHA	OK	1969-72	530.52	0.00	100.00	0.00	8.90
5145	CHICKASHA	OK	1969-72	103.60	0.00	100.00	0.00	9.00
5146	CHICKASHA	OK	1969-72	307.21	0.00	100.00	0.00	9.00
R-5	CHICKASHA	OK	1967-72	9.61	0.00	100.00	0.00	3.40
R-6	CHICKASHA	OK	1967-72	11.01	0.00	100.00	0.00	4.90
R-7	CHICKASHA	OK	1967-72	7.77	0.00	100.00	0.00	4.80
R-8	CHICKASHA	OK	1967-72	7.46	0.00	100.00	0.00	6.00
C-1	CHICKASHA	OK	1966-72	7.23	100.00	0.00	0.00	0.50
C-3	CHICKASHA	OK	1966-72	17.92	100.00	0.00	0.00	0.20
C-4	CHICKASHA	OK	1966-72	12.12	100.00	0.00	0.00	0.20
C-5	CHICKASHA	OK	1966-72	5.15	100.00	0.00	0.00	0.40
C-6	CHICKASHA	OK	1966-72	5.26	100.00	0.00	0.00	0.40
C-7	CHICKASHA	OK	1966-72	10.72	100.00	0.00	0.00	0.20
C-8	CHICKASHA	OK	1966-72	11.03	100.00	0.00	0.00	4.40
W-4	OXFORD	MS	1966-71	639.73	14.00	39.00	47.00	10.40
W-5	OXFORD	MS	1966-71	455.84	12.00	58.00	30.00	9.00
W-5A	OXFORD	MS	1971-72	6.35	100.00	0.00	0.00	4.50
W-1	TREYNOR	IA	1964-71	30.04	100.00	0.00	0.00	9.20
W-2	TREYNOR	IA	1964-71	33.41	100.00	0.00	0.00	6.40
W-3	TREYNOR	IA	1965-71	43.25	0.00	100.00	0.00	8.90

TABLE 2. GENERAL INFORMATION ABOUT USGS AND SCS WATERSHEDS USED IN TESTING MUSLE WITH SIMULATED RUNOFF

WATERSHED	LOCATION	ST.	PERIOD OF RECORD	DRAINAGE AREA KM2	******** LAND USE % CROP LAND	PASTURE RANGE	******* FOREST WOODS	AVERAGE SLOPE %
BIG SANDY CR.	BRIDGEPORT	TX	1968-72	513.00	0.10	0.90	0.00	4.00
CLEAR CR.	SANGER	TX	1968-72	388.50	0.35	0.65	0.00	3.50
LITTLE ELM CR.	AUBREY	TX	1966-72	121.99	0.50	0.50	0.00	3.00
PIN OAK CR.	HUBBARD	TX	1964-71	28.51	0.30	0.70	0.00	3.00
HONEY CR. #11	MCKINNEY	TX	1952-67	4.97	0.55	0.45	0.00	7.46
HONEY CR. #12	MCKINNEY	TX	1952-69	3.26	0.61	0.39	0.00	3.88
CLEAR FORK #7	POOLVILLE	TX	1955-69	6.32	0.00	1.00	0.00	6.08
CLEAR FORK #10	WEATHERFORD	TX	1955-68	11.01	0.04	0.96	0.00	7.11
ELM FORK #11-E	GAINESVILLE	TX	1958-68	4.84	0.09	0.91	0.00	5.10
CHAMBERS CR. #37	CLEBURNE	TX	1960-69	5.02	0.07	0.93	0.00	5.07
CHAMBERS CR. #101-A	FROST	TX	1960-68	6.06	0.54	0.46	0.00	3.74
ESCONDIDO CR. #1	KENEDY	TX	1958-69	7.33	0.30	0.70	0.00	4.59
CALAVERAS CR. #6	SAN ANTONIO	TX	1956-68	17.35	0.30	0.70	0.00	3.07
COWELL LAKE	BIG HILL	KY	1954-74	2.77	0.00	0.00	1.00	36.00
A. SMITH POND	HOLLY SPRINGS	MS	1954-75	0.05	0.20	0.68	0.12	12.00
W. MURPHY POND	HOLLY SPRINGS	MS	1954-75	0.65	0.10	0.90	0.00	11.90
SANTA CRUZ #4	CHIMAYO	NM	1962-75	6.37	0.00	1.00	0.00	25.40
SANTA CRUZ #5	CHIMAYO	NM	1962-74	3.32	0.00	1.00	0.00	19.80
SANTA CRUZ #6	CHIMAYO	NM	1962-75	9.01	0.00	1.00	0.00	21.30
BERNALILLO DAM	BERNALILLO	NM	1955-75	10.31	0.00	1.00	0.00	25.50
E. WAGNER POND	EASTON	KS	1957-73	1.68	0.65	0.35	0.00	7.10
J. DEFRIES POND	TONGANOXIE	KS	1960-73	0.60	0.77	0.23	0.00	9.20
O. HARVEY POND	TONGANOXIE	KS	1964-73	0.62	0.60	0.00	0.40	7.60
LAKE DABINAWA	LAWRENCE	KS	1959-74	9.69	0.33	0.61	0.06	7.80
MILL CREEK #17	SULPHUR	OK	1959-72	4.12	0.01	0.99	0.00	4.20
CUMMINS CR. #6	GIDDINGS	TX	1958-69	7.15	0.08	0.92	0.00	2.12
MUKEWATER CR. #9	BANGS	TX	1961-70	11.78	0.22	0.78	0.00	3.43
GREEN CR. #1	DUBLIN	TX	1955-67	8.75	0.29	0.71	0.00	4.16
SULPHUR CR. #3	LAMPASAS	TX	1959-68	27.40	0.00	1.00	0.00	3.01
DEEP CR. #8	BRADY	TX	1951-66	10.41	0.14	0.86	0.00	4.62
LOWER SAN SABA #9	SAN SABA	TX	1960-73	7.46	0.04	0.96	0.00	4.07
DIABLO ARROYO	MCNARY	TX	1960-70	76.43	0.00	1.00	0.00	13.50
COW BAYOU #3	MOODY	TX	1955-75	3.42	0.29	0.71	0.00	6.33
COW BAYOU #4	BRUCEVILLE	TX	1956-69	13.47	0.09	0.91	0.00	7.10
ASHLAND RES.	ASHLAND	MO	1951-71	9.69	0.58	0.25	0.17	8.20
BAILEY RES.	STURGEON	MO	1965-75	0.91	0.48	0.48	0.04	5.20
CHIGLEY SANDY #4	WYNNEWOOD	OK	1955-74	9.76	0.01	0.63	0.36	5.70
BIG WEWOKA #17	WEWOKA	OK	1963-73	5.34	0.00	0.41	0.59	8.50
BIG WEWOKA #36	HOLDENVILLE	OK	1960-74	5.41	0.15	0.85	0.00	4.20
WILDHORSE #1	DAVIS	OK	1959-73	2.36	0.01	0.97	0.02	6.70
OWL CREEK #1	WAYNE	OK	1959-73	1.48	0.16	0.84	0.00	4.60
SAUTEECREEK #13	CLEVELAND	GA	1960-70	7.61	0.00	0.05	0.95	25.20
SOUTH RIVER #4	GREENVILLE	VA	1959-71	8.42	0.00	0.19	0.81	17.90

TABLE 3. RESULTS OF TESTS USING MEASURED RUNOFF

WATERSHED	RAINFALL (MM)	RUNOFF (MM)	SEDIMENT YIELD (T/HA)		STANDARD DEVIATION (T)		R**2	REGRESSION SLOPE
			MEA.	PRED.	MEA.	PRED.		
A	912.	196.8	1.50	1.47	6.49	5.46	0.89	1.12
B	968.	209.8	3.12	3.34	134.27	150.60	0.93	0.86
D	897.	196.3	0.96	1.93	139.80	235.87	0.88	0.55
G	884.	175.0	1.43	1.70	570.63	770.21	0.90	0.70
J	922.	148.1	3.97	2.94	1038.79	828.27	0.95	1.22
SW-2	912.	151.1	10.76	13.47	2.65	3.06	0.93	0.84
SW-3	914.	124.0	11.93	11.37	4.73	4.20	0.96	1.10
SW-5	925.	298.5	34.30	34.57	10.80	19.16	0.97	1.05
SW-6	904.	205.2	35.19	36.89	10.61	10.16	0.90	0.99
SW-7	932.	192.1	23.09	21.18	7.01	5.18	0.83	1.23
SW-11	932.	153.9	4.28	5.02	1.89	1.90	0.88	0.94
SW-12	904.	106.9	0.34	0.34	0.14	0.1	0.82	1.22
SW-13	902.	185.4	25.56	25.11	7.09	7.04	0.90	1.11
SW-16	927.	246.1	24.43	26.00	6.46	6.22	0.97	1.02
SW-17	902.	227.8	20.69	19.86	6.07	5.31	0.94	1.11
SW-18	932.	177.0	5.65	6.81	1.42	1.79	0.94	0.77
Y	955.	186.9	9.77	11.41	117.94	133.36	0.94	0.85
Y	851.	135.9	1.01	1.26	35.56	42.18	0.92	0.81
Y-2	978.	304.8	2.80	2.91	20.96	19.58	0.92	1.03
Y-2	851.	134.1	0.9[illegible]	1.57	14.97	19.60	0.89	0.73
Y-6	963.	189.2	14.80	15.09	18.23	14.42	0.90	1.21
Y-6	853.	92.5	1.0	1.28	3.62	4.25	0.96	0.83
Y-8	828.	96.0	1.26	1.37	5.00	5.23	0.99	0.95
Y-10	940.	170.7	7.76	10.58	8.63	10.98	0.95	0.76
Y-10	892.	155.2	1.55	1.61	5.09	4.83	0.99	1.05
Y-13	825.	64.3	1.01	1.10	1.06	0.97	0.94	1.06
Y-14	823.	85.1	2.67	2.20	2.08	2.09	0.96	0.97
W-1	960.	231.9	21.0[illegible]	31.52	195.95	264.00	0.92	0.71
W-1	851.	156.5	3.09	4.04	59.60	74.03	0.89	0.76
W-2	947.	24[illegible].3	7.08	6.37	45.18	38.92	0.87	1.09
W-6	935.	150.9	0.65	0.67	2.08	1.20	0.82	1.47
W-8	914.	159.0	14.40	17.88	36.11	39.10	0.95	0.90
W-10	1049.	242.9	21.59	19.93	13.88	12.70	0.94	1.06
W-12	853.	86.4	1.01	0.99	0.98	0.99	0.95	0.97
W-13	853.	75.9	0.56	0.56	0.96	0.89	0.92	1.04
W-3	574.	84.3	15.94	25.65	801.96	1138.59	0.92	0.65
W-5	574.	84.3	7.94	8.99	466.30	529.80	0.93	0.85
68.001	508.	81.3	0.67	0.83	5095.74	2767.97	0.86	1.71
68.004	787.	254.0	0.78	1.01	317.39	303.06	0.48	1.87
68.002	483.	83.8	1.17	1.17	1694.65	943.49	0.83	1.63
68.003	483.	63.5	1.19	1.32	1160.31	881.80	0.72	1.12
5140	787.	60.2	1.30	1.21	1176.64	801.06	0.63	1.16
5141	787.	35.8	[illegible]	[illegible]	927.16	747.53	0.89	1.17
5142	787.	36.1	1.08	1.17	35.29	26.58	0.65	1.07
5143	787.	15.7	0.22	0.25	22.14	18.6[illegible]	0.94	1.15
5144	787.	46.2	4.90	3.92	205.93	142.43	0.85	1.33
5145	787.	42.5	5.00	5.07	129.73	90.45	0.62	1.14
5146	787.	34.3	1.05	0.96	111.59	83.55	0.75	1.15
R-5	787.	27.2	0.04	1.05	4.26	[illegible].16	0.52	1.19
R-6	787.	25.7	0.0	0.10	1.55	0.5[illegible]	0.74	0.94
R-7	787.	116.6	2.47	3.25	3.84	3.33	0.73	0.98
R-8	787.	107.2	[illegible].00	3.47	6.06	4.1[illegible]	0.90	1.30
C-1	787.	61.8	0.83	0.94	1.46	1.25	0.23	0.56
C-3	787.	87.1	2.85	2.38	12.61	6.48	0.48	1.36
C-4	787.	70.1	2.15	1.75	7.87	4.08	0.39	1.20
C-5	787.	30.0	0.45	0.65	2.43	2.84	0.71	0.72
C-6	787.	36.8	0.83	0.96	3.61	3.12	0.79	1.03
C-7	787.	[illegible]7.9	2.3[illegible]	1.91	8.96	3.81	0.37	1.43
C-8	787.	16.3	0.56	0.36	7.55	3.91	0.96	1.89
W-4	1247.	139.7	2.56	2.38	283.95	215.01	0.86	1.23
W-5	1267.	284.0	7.35	12.37	374.67	546.13	0.93	0.66
W-5A	1267.	284.0	12.13	13.90	6.44	4.88	0.91	1.26
W-1	874.	295.7	73.98	122.62	329.31	404.61	0.85	0.75
W-2	864.	190.1	58.0[illegible]	95.50	276.70	359.25	0.91	0.74
W-3	838.	119.4	1.37	1.08	17.60	12.43	0.89	1.34

TABLE 4. RESULTS OF TESTS USING SIMULATED RUNOFF

WATERSHED	RAINFALL (MM)	RUNOFF (MM)		SEDIMENT YIELD (T/HA)		
		MEA.	PRED.	MEA.	PRED.	GULLY
BIG SANDY CR.	795.	53.3	53.3	0.45	0.47	0.11
CLEAR CR.	1052.	109.2	109.2	4.04	3.21	0.65
LITTLE ELM CR.	986.	195.6	195.6	3.34	2.76	0.16
PIN OAK CR.	1001.	208.3	208.3	4.15	3.52	0.11
HONEY CR. #11	914.	190.5	190.5	13.85	15.60	1.77
HONEY CR. #12	950.	193.0	193.0	10.96	12.91	0.63
CLEAR FORK #7	31.	88.9	88.9	13.19	12.96	0.06
CLEAR FORK #10	20.	6.4	56.4	7.62	7.53	0.83
ELM FORK #11-C	920.	121.9	121.[illegible]	[illegible]	8.41	3.36
CHAMBERS CR. #37	780.	109.2	109.2	1.57	3.68	1.86
CHAMBERS CR. #101-A	900.	177.8	177.8	7.91	8.61	0.16
ESCONDIDO #1	7[illegible].	63.5	63.5	9.01	4.93	0.94
CALAVERAS #6	747.	50.8	50.8	2.47	1.59	
CUMMINS #6	927.	177.3	177.8	1.50	1.17	
MUKEWATER #9	658.	63.5	63.5	1.39	1.46	0.11
GREEN CR. #1	734.	78.7	78.7	2.58	4.71	0.29
SULPHUR CR. #3	787.	88.9	88.9	0.25	0.27	
DEEP CR. #8	663.	63.5	63.5	1.61	1.32	
LOWER SAN SABA #9	658.	63.5	63.5	1.39	1.43	0.07
DIABLO ARROYO	200.	7.6	7.6	3.97	3.47	
COW BAYOU #3	871.	127.0	127.0	16.16	15.74	2.47
COW BAYOU #4	889.	134.6	134.6	4.98	4.75	0.47
ASHLAND RES.	975.	254.0	144.8	3.14	2.69	
BAILEY RES.	960.	254.0	167.6	4.48	4.26	
QUIGLEY SANDY #4	940.	109.2	180.3	6.73	4.39	0.58
BIG NEVOKA #17	969.	111.8	99.1	5.60	2.51	0.67
BIG NEVOKA #36	968.	152.4	149.9	3.36	5.51	0.36
WILDHORSE #1	914.	104.1	147.3	3.14	5.74	0.81
OWL CREEK #1	889.	109.2	73.7	13.00	3.32	0.00
SANTEE CREEK #13	1605.	929.6	797.6	22.42	26.45	
SOUTH RIVER #4	965.	363.2	256.5	0.09	0.38	
CORNELL LAKE	1206.	482.6	429.3	1.43	1.52	
A. SMITH POND	1367.	269.2	284.5	26.90	25.11	
W. MURPHY POND	1367.	269.2	279.4	15.92	15.92	
SANTA CRUZ R. #4	244.	2.5	6.3	24.66	10.87	
SANTA CRUZ R. #5	244.	2.5	6.3	21.97	9.21	
SANTA CRUZ R. #5	244.	2.5	6.3	21.97	9.21	
BERNALILLO DAM	305.	10.2	39.1	13.45	7.53	
F. WAGNER POND	889.	165.1	160.0	12.11	10.54	
J. DEFRIES POND	889.	165.1	175.3	14.12	20.69	
D. HARVEY POND	889.	165.1	175.3	22.64	27.80	
LAKE DIKIDAWA	[illegible]	152.4	129.5	11.43	8.74	
MILL CREEK #17	365.	139.7	111.8	6.28	1.86	0.00

DEVELOPING A USLE COVER-MANAGEMENT (C) FACTOR PROCEDURE FOR FOREST CONDITIONS

George E. Dissmeyer[1/]

ABSTRACT

The cooperative effort between the Forest Service, SEA-AR, and the SCS has resulted in a new procedure for developing the USLE Cover-Management (C) Factor Procedure for Forest Conditions. The new procedure for estimating the values for the USLE's C factor for forest conditions is described. Values for C are estimated by evaluating nine sub-factors. The procedure was validated with data from 39 research watersheds in the Southeast and provides reasonably good estimates of erosion. Values from the new procedure are recommended instead of those from tables 11 and 12 in Agricultural Handbook 537.

INTRODUCTION

A cooperative effort between the Forest Service, SEA-AR, and the SCS produced a new procedure for assigning a Universal Soil Loss Equation (USLE) cover-management (C) factor to forest conditions. The four-year effort was culminated in an article soon to be published in the Journal of Soil and Water Conservation (Dissmeyer and Foster 1981) and in a handbook published by a USDA Forest Service, Southeastern Area, Atlanta, Georgia (Dissmeyer and Foster 1980). The purpose of this paper is to describe the steps taken in this cooperative effort to produce the new procedure and to present the new cover-management factor procedure to this workshop.

The cooperative effort started with a meeting of representatives from the three agencies concerned about predicting erosion from forest lands in the spring of 1977. Questions had been raised as to what procedure would be used in predicting erosion from forest lands--the USLE (Wischmeier and Smith 1978) or some other procedure. Concerns had been raised about the accuracy of the USLE in predicting erosion rates for the varied conditions found in the forest environment (Wischmeier 1975). The USLE had received substantial criticism from researchers in erosion and sedimentation from forest lands. Using the information and procedures available at that time, the USLE was judged to be over-predicting erosion for a variety of conditions.

Therefore, a group of hydrologists from the Forest Service and experts in the USLE from the Soil Conservation Service and SEA-AR met in South Carolina to inspect a variety of forest management situations and discuss the suitability of the USLE for predicting erosion in these conditions. Those who were in

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[1/] Staff hydrologist, USDA Forest Service, Southeastern Area, Atlanta, Georgia.

attendance included John Holeman (SCS-WO), E. C. Nicholas (SCS-Fort Worth), George R. Foster (SEA-AR, Purdue University), Marv Meyer (Forest Service-WO), and myself, plus two other Forest Service hydrologists working in the erosion field. After two days in the field, the group realized that several sub-factors of the cover-management factor were operating in both the forest environment and the agriculture environment, but were not available in the literature for foresters. The group found the situation warranted modifying the USLE cover-management factor to incorporate the agricultural experience into a procedure for prediction erosion for forest lands. As a result, over the past four years, George Foster and I have cooperated in modifying the cover-factor procedure for forest conditions with substantial input from E. C. Nicholas.

After viewing the forestry situation, I went to Purdue University and inspected the agricultural situation so that I could understand and appreciate how these sub-factors were operating in those conditions. George Foster and I visited a cross-section of agricultural conditions where George described what sub-factors were operating and how they were evaluated. We then interpreted and extrapolated data from the agricultural situation and applied it to the forest situations we saw in South Carolina. I also identified one sub-factor that was operating in the forest situation that was not operating in the agricultural situation, namely steps. We decided to adopt the component sub-factor procedure first developed by Wischmeier (1973, 1975, 1979) and Wischmeier and Smith (1978) for agriculture land where the component sub-factor affecting C are evaluated and used to develop a composite C. Such an approach was judged prudent, because there was a wide variety of conditions present even when land was treated with the same piece of equipment. A great deal of flexibility had to be built into the system to handle this heterogeneous situation. A preliminary procedure was developed.

After the preliminary procedure was developed, Foster, Nicholas, and I again met in the field to discuss the variety of forest management conditions and the application of the system. During this field session, ideas were exchanged on how to interpret conditions, discussed which sub-factors were operating in a given situation, and how to provide guidance to practitioners in applying the system. After two days in the field, the three of us had reached a common understanding of interpretations and of approach in applying the procedure. The resulting procedure was ready for field testing or validation.

I validated the procedure using 39 research watersheds in the Southeast; the results are discussed later in the paper. I contacted the researchers responsible for these watersheds and secured permission to validate the procedure using their watershed data. The data had not been published at that time. I visited each watershed and carefully inspected the watershed using the new procedure and all the latest techniques for applying the USLE. The validation found, in essence, that the new procedure gave reasonably good predictions of erosion.

I then met with George Foster, and we outlined a paper and a handbook on the new procedure. However, before we prepared these two items for publication, George Foster, E. C. Nicholas, and I again met and discussed the procedure in the field where we discussed some refinements in interpretation and application of the procedure. A slide presentation was developed and presented at an inter-agency USLE Workshop in Fort Worth in November, 1979. The procedure

was well received at the meeting, and the publications were then prepared and are in the process of being published at this time (Dissmeyer and Foster 1980, 1981).

This summarizes the steps we took in developing this new procedure for forest lands. It is a procedure that I would recommend to those who are trying to adapt the USLE to range conditions. Using the component sub-factor approach allows a great deal of flexibility in handling the wide variety of conditions that can be found in range and desert conditions. We found in forest land that a standard C could not be assigned from a table because of the wide variation in conditions produced by a piece of equipment. Only careful on-site inspection of each location could develop a reasonably accurate C factor. Foster and I believe that this is a good way to identify which sub-factors are operating and how management affects the sub-factors and the resultant erosion rate.

The following material is quoted directly from the forthcoming Journal article mentioned earlier (Dissmeyer and Foster 1981). I have done this so that you will have information in the proceedings of this workshop, thus saving you the effort of securing a copy of that paper. The only modification I have made in the following material is to change the citation numbers to fit the needs of this paper.

The C factor values in Agriculture Handbook 537 for forest conditions are based on many of the same principles discussed below. However, since those values were developed, additional experience in applying the USLE to forest land, a better understanding of erosion processes on forest land, and data for validation have led to improved ways of estimating C, and thus improved erosion estimates.

FOREST SUB-FACTORS

The major sub-factors operating in the forest environment are: (1) amount of bare soil, or conversely, ground cover, (2) canopy, (3) soil reconsolidation, (4) high organic content, (5) fine roots, (6) residual binding effect, (7) on-site storage, (8) steps, and (9) contour tillage. Sub-factors 1, 2, 3, 5, 6, and 7 have direct counterparts in agricultural practices, especially conservation tillage. The eighth does not occur in most agricultural situations. The ninth is part of the supporting practices P factor of the USLE. A value for the composite C factor is a product of values for each of the sub-factors operating in a given forest situation.

Some sub-factor names were changed from common ones for erosion processes on agriculture land so they would better describe forest situations. Also, some sub-factor relationships for agricultural conditions have been modified for better application to forest situations.

BARE SOIL SUB-FACTOR

Erosion is a function of the amount of exposed soil. Cover such as litter, slash, logs, and surface rock protects the soil from the erosive forces of raindrop impact and runoff. Protected and undisturbed forest soils have

infiltration rates that usually exceed rainfall intensity (Lull and Reinhart 1972). Exposed forest soils are subject to soil detachment by raindrop impact. Also, they yield surface runoff, which potentially erodes soil and transports detached soil from the slope.

The relationship for the bare soil sub-factor is shown in Figure 1. It is an adaptation of Wischmeier's (1975) curve for the effect of surface cover. The curve was adjusted for ground cover greater than 80 percent (less than 20 percent have ground) to give no erosion at 100 percent ground cover (zero percent bare soil). In the forest, a zero percent bare soil is usually a healed or an undisturbed condition. Generally, no runoff occurs, thus no erosion. In contrast, most agricultural soils are regularly tilled; even with zero bare soil, runoff and slight erosion can occur, which is reflected by 0.04 value from Wischmeier's curve at zero bare ground.

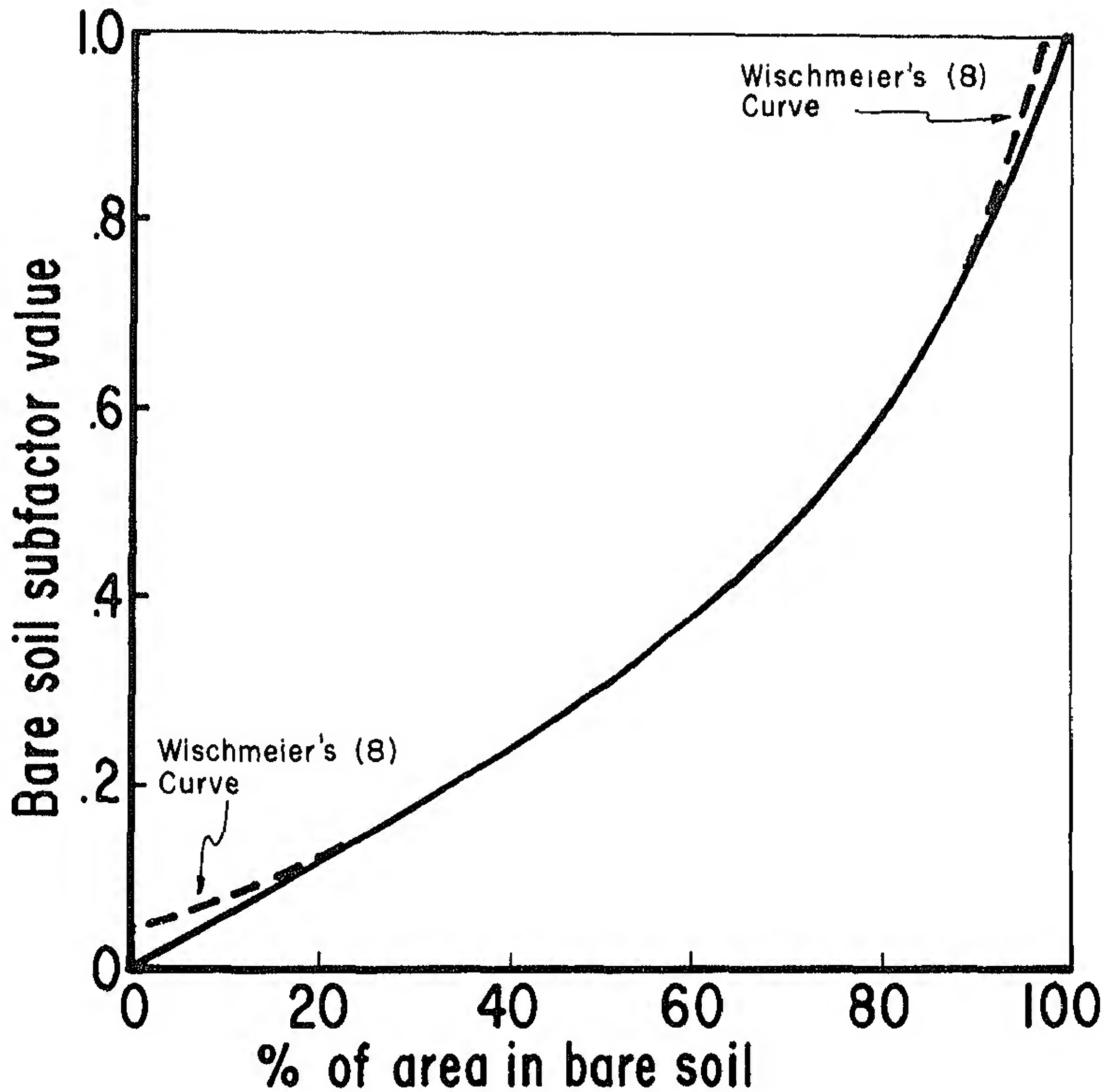

Figure 1.--The bare soil sub-factor.

Bare soil in forests tends to be in patches randomly distributed over the area. These patches are usually much larger and much fewer than the numerous small bare spots in agricultural situations that are typically uniformly distributed. Runoff is generally more uniform from both bare and mulch-covered areas of agricultural soils than from the bare and covered areas of forest soils. Covered patches in forests often yield no runoff or sediment. Runoff and sediment from bare patches reaching the toe of the slope in forest situations depends on the interconnection of bare areas. Runoff from a bare area into a covered area may be completely absorbed. This further warranted the modification of Wischmeier's (1975) curve below 20 percent bare soil.

A patch of ground cover in a largely exposed area usually has a very high ground cover percentage within its boundaries, and this area is not eroding. Surface runoff is usually directed around such patches.

Wischmeier's (1975) mulch effect curve may be used instead of Figure 1 if areas of bare soil are small like those for agricultural situations, if runoff occurs uniformly from bare and covered soils, and if runoff occurs when the soil is completely covered.

CANOPY SUB-FACTOR

Vegetal canopy intercepts rainfall and collects water on its foliage. Drops falling from the canopy may be larger than the original raindrops, but when they fall from a low canopy, the energy of the drops reaching the soil surface is less than that of rainfall in open areas. Also, some of the intercepted rainfall never reaches the ground but is evaporated during and after the storm. Some of the intercepted rainfall reaches the ground as stemflow and may contribute to runoff. Figure 2, from Wischmeier (1975), gives the values for the canopy sub-factor that depend on foliage density and average drop height. Figure 3 illustrates the average drop height, which is approximately the midpoint of the canopies, for several types of canopies.

This sub-factor applies only to the canopy above bare soil. Canopy over litter is not included, because the surface cover is the controlling factor. Canopy is evaluated by estimating the percentage of bare soil having canopy over it and the average drop height of the canopy. The open area within the canopy where rain can pass is not counted as part of the canopy.

Evaluation of canopy in forestry situations is different than for agriculture (Wischmeier 1975). In forests, canopy often is not uniformly distributed, nor is the bare soil. Areas of forest soil with undisturbed litter cover usually yield no surface runoff, whereas covered agricultural soil often does. Wischmeier (1975) reduced the canopy factor, because water drops falling from the canopy were assumed to strike uniformly distributed ground cover. The canopy over ground cover is ineffective. Typically, in forests, ground cover under canopy is totally protective, usually yielding no surface runoff or erosion. Therefore, only canopy over bare soil is given full credit.

Some forest, brushland, and desert conditions may be encountered where canopy and bare soil are uniformly distributed, as in agricultural situations where the canopy cover over bare soil may be difficult to estimate. Wischmeier

(1975) provides a procedure for reducing canopy effect for this situation. Both the above and Wischmeier's procedures produce the same answer.

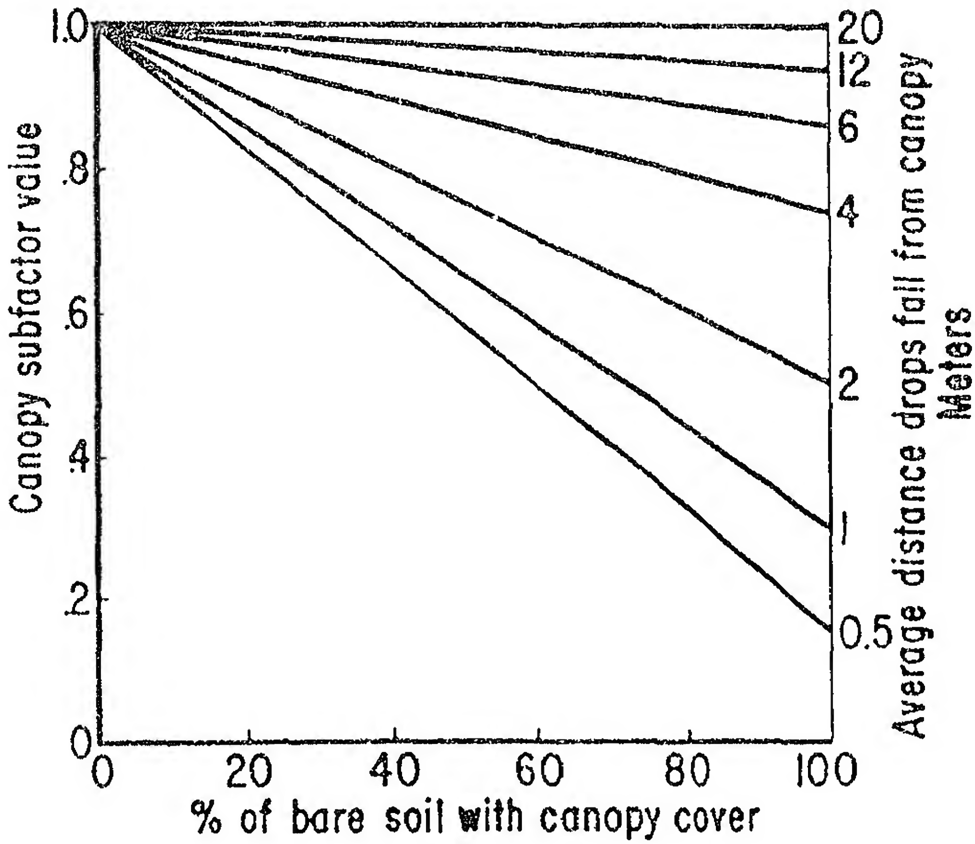

Figure 2.--The canopy sub-factor.

SOIL RECONSOLIDATION SUB-FACTOR

Generally, soil reconsolidates and becomes less erodible over time after land is retired from tillage. This effect was analyzed using data from erosion plots that were tilled and then left untilled for several years. Soil loss from these plots was studied for trends. The ratio of annual soil loss to the observed value of R, erosivity factor of the USLE, for these plots is proportional to the USLE soil erodibility factor K. If these ratios remain constant with time following retirement from tillage, soil erodibility has not changed, which occurred for soil studied at Guthrie, Oklahoma and Statesville, North Carolina. However, these ratios decreased significantly with time at Zanesville, Ohio and Tyler, Texas,[2] indicating that soil erodibility decreased over time since retirement from tillage (Figure 4).

[2] Data on file at USDA-National Runoff and Soil Loss Data Center, Purdue University, West Lafayette, Indiana.

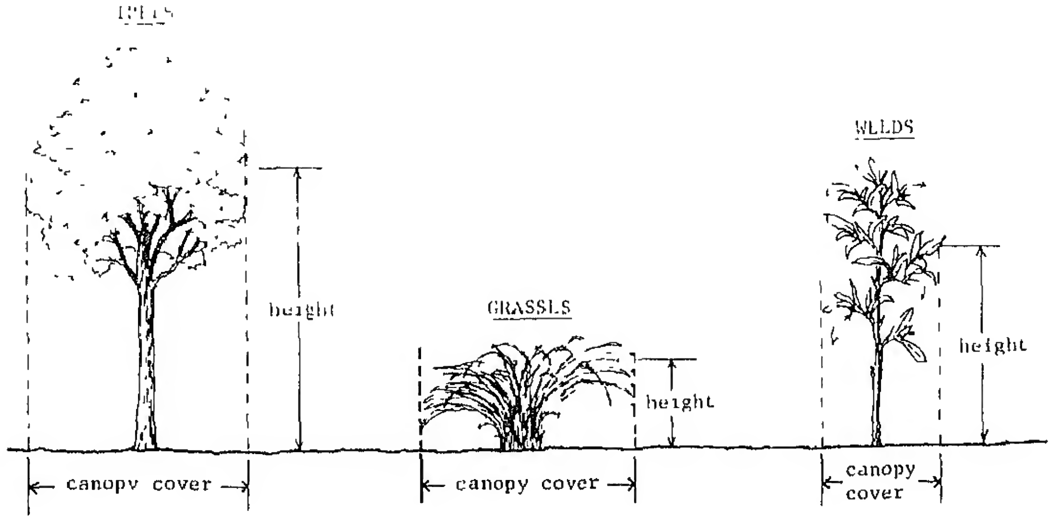

Figure 3.--Canopy effect and typical drop heights for three types of vegetation.

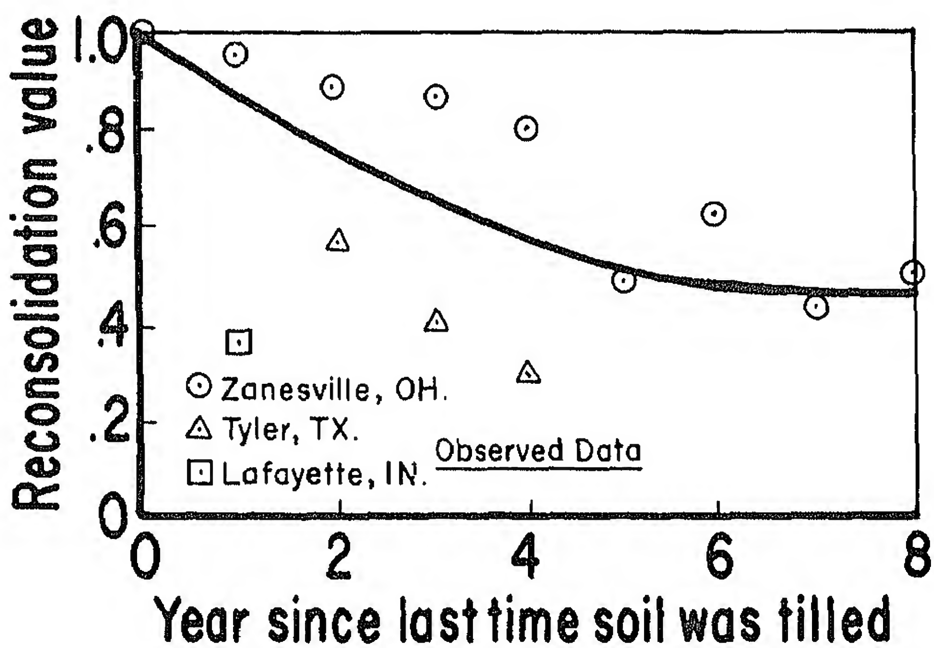

Figure 4.--The sub-factor for soil reconsolidation.

Soil loss at Zanesville decreased over a 7-year period and leveled off at 45 percent of that for the first two years following retirement from tillage. Wischmeier (1975) used the Zanesville data to conclude that undisturbed soil is 0.45 as erodible as continuously tilled soil. At Tyler, erodibility decreased in four years to 30 percent of that for the first year following retirement. When the soil was returned to cultivation, soil loss immediately

increased to a level about 4 times the rate before cultivation. Similar results were obtained for erosion plots under simulated rainfall and added inflow to simulate longer slope lengths (Foster et al. 1981). Erosion from soil that had not been tilled for a year was 35 percent of that immediately following tillage.

Thus, we concluded that undisturbed soils are generally less erodible, and that erosion decreases over time following retirement from tillage, as shown in Figure 4. However, the effect is soil dependent. This soil type sub-factor is necesssary, because the soil erodibility factor K of the USLE is derived from tilled soils in continuous fallow.

For untilled forest soils, the soil reconsolidation sub-factor is 0.45. However, if the soil is tilled by disking, bedding, or rootraking when preparing a site for tree planting, this sub-factor begins at 1.0 and decreases with time after tillage.

HIGH ORGANIC CONTENT SUB-FACTOR

Under permanent forest, topsoil accumulates a high organic matter content that is not considered in the USLE soil erodibility nomograph (Wischmeier and Smith 1978), which only goes as high as 4 percent organic matter. With good management, organic matter content can be maintained in agricultural soils, but it will not be as high as that in a permanent forest. This higher organic content results in permanent forest soils being less erodible. Wischmeier and Smith (1978) recommend multiplying by a sub-factor of 0.7 to account for the high organic matter content of permanent forest soils. However, forests on recently abandoned farms have not had time for high organic matter contents to accumulate in the topsoil; thus, no adjustment is made. This latter situation is common in Piedmont and Coastal Plain regions in the South.

FINE ROOT SUB-FACTOR

A dense mat of fine roots is usually present in the top 50 millimeters of forest soils. Even after the trees are removed, the residual root mat will partially protect soil from the erosive forces of rainfall and runoff by holding the soil in place. Few data are available on this effect. Thus, we used Wischmeier's (1975) curve for the effect of a grass root network to describe it. His curve was used after the reconsolidation effect was removed by dividing by 0.45, since he had combined the effects of both reconsolidation and grass root network. The fine root mat effect of trees is described by the curve for lateral rooted vegetation in Figure 5.

Sometimes, the site is exposed by removal of the surface organic material while the topsoil, with its fine root mat, is left in place. Where equipment has removed the topsoil, the fine root mat is usually eliminated. The observer estimates the percentage of the bare soil that has this effective root mat in place. Use the percent of total area rather than percent of bare soil, if the total area is contributing runoff, as in agricultural situations.

The second application of this sub-factor is to credit invading vegetation for its new fine root mat on sites where the original fine root mat has been

removed or has been mutilated by tillage. The expanding root systems of invading weeds, grasses, brush, and trees on these disturbed soils reduce erosion within the area containing these roots. The area influenced by these roots is assumed to be the area under the canopy of the plant (Fig. 6). If the plant is grazed and the canopy partially consumed, the observer may estimate the area of roots by visualizing the normal crown area for the plant.

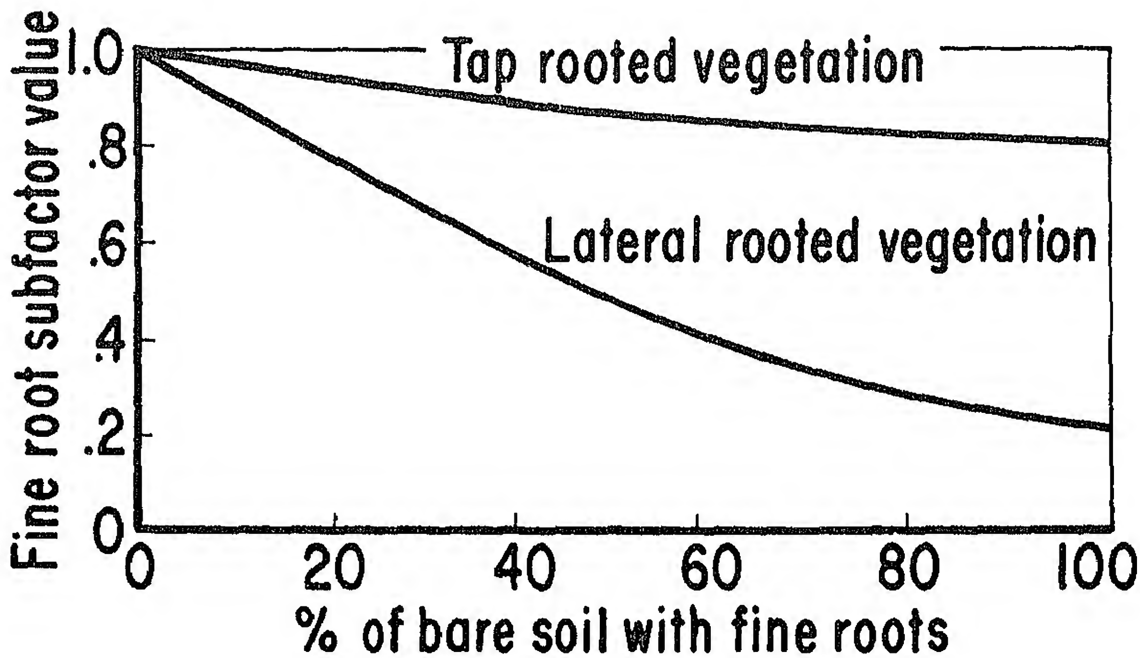

Figure 5.--The sub-factor for fine roots in the top 30 to 50 mm of soil.

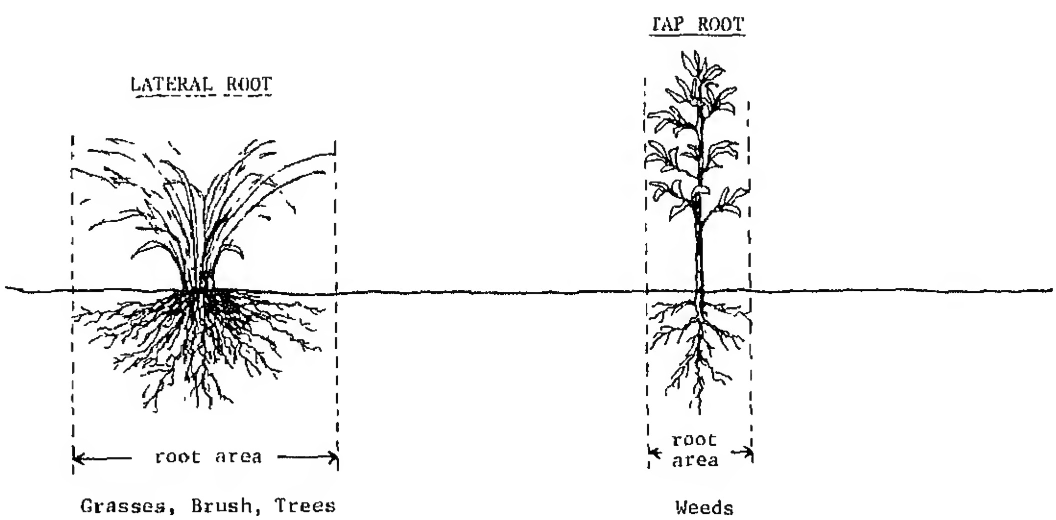

Figure 6.--Area influenced by fine roots of invading vegetation.

Grasses and other lateral-rooted plants are more effective than tap-rooted plants such as broadleaf weeds. Therefore, the observer, when evaluating this sub-factor, must estimate the percentage of the disturbed bare soil that is now occupied by invading vegetation and what proportion of this vegetation is lateral-rooted. If only a portion of the vegetation is lateral-rooted, the observer must interpolate between the curves in Figure 5.

RESIDUAL BINDING EFFECT SUB-FACTOR

The erosion response of a soil depends on the soil's recent history. That is, there is a residual or carryover effect when land use or condition changes. When a soil that has not been tilled for some time is cultivated, erosion immediately after it is first tilled may be much less than it will be in 2 to 3 years later (Wischmeier and Smith 1978). The soil, at first, has fairly good structure. Fine roots and organic matter bind the soil into more stable aggregates. With time, this effect disappears, and the soil becomes more erodible.

The curves in Figure 7 describe this effect. They were adapted from USLE data for the residual effect of turned sod (Wischmeier and Smith 1978). The magnitude of the effect and its duration is a function of the amount of roots and organic matter in the soil at the time of tillage and the rate of decay of the roots and organic matter plus structure and permeability of the subsoil.

Curve a in Figure 7 is similar to Wischmeier and Smith's (1978) relationship for the residual effect of turned sod for a hay yield of 7-11 t/ha, except that the duration of the effect is doubled because the woody roots and forest debris are assumed to decay more slowly than roots from sod. Burroughs and Thomas (1977) reported that Douglas-fir roots less than one centimeter in diameter lost 82 percent of their tensils strength 30 months after the tree was cut. Ziemer and Swanston (1977) noted a similar pattern for very small (2-5 mm) hemlock and Sitka spruce roots in southeast Alaska. Longer roots (10-25 mm) experience a less dramatic reduction in strength, apparently because of resin content. These roots retain 60 percent of their strength after 10 years. Furthermore, Pritchett (1977) reports that the weight of organic material on the forest floor ranges from approximately 30 t/ha to over 100 t/ha depending upon forest type. The other curves in Figure 7 are similar in concept to Wischmeier and Smith's for reduced hay yield with duration of effect doubled.

ON-SITE DEPRESSION STORAGE SUB-FACTOR

Not all detached soil may be delivered to the toe of the slope; a portion may be stored locally in depressions. On-site storage opportunites include depressions such as stump holes, berms turned up by tractor treads, dips created by bulldozers, slits cut by choppers, rolled up debris, and voids between clods, as illustrated in Figure 8. Coefficients for on-site depression storage (roughness) were developed from USLE soil loss ratios (Wischmeier and Smith 1978), Wischmeier's (1973) analysis of conservation tillage systems, and Wischmeier's notes (1979). The ratio of soil loss for the fallow period to that for the seed bed period for agricultural situations is primarily a measure of the effect of depression storage. Wischmeier and Smith (1978) suggest a value of 0.5 to 0.8 for freshly plowed land. Values in Figure 8 were developed by comparing forestry conditions with agricultural conditions having similar roughness characteristics.

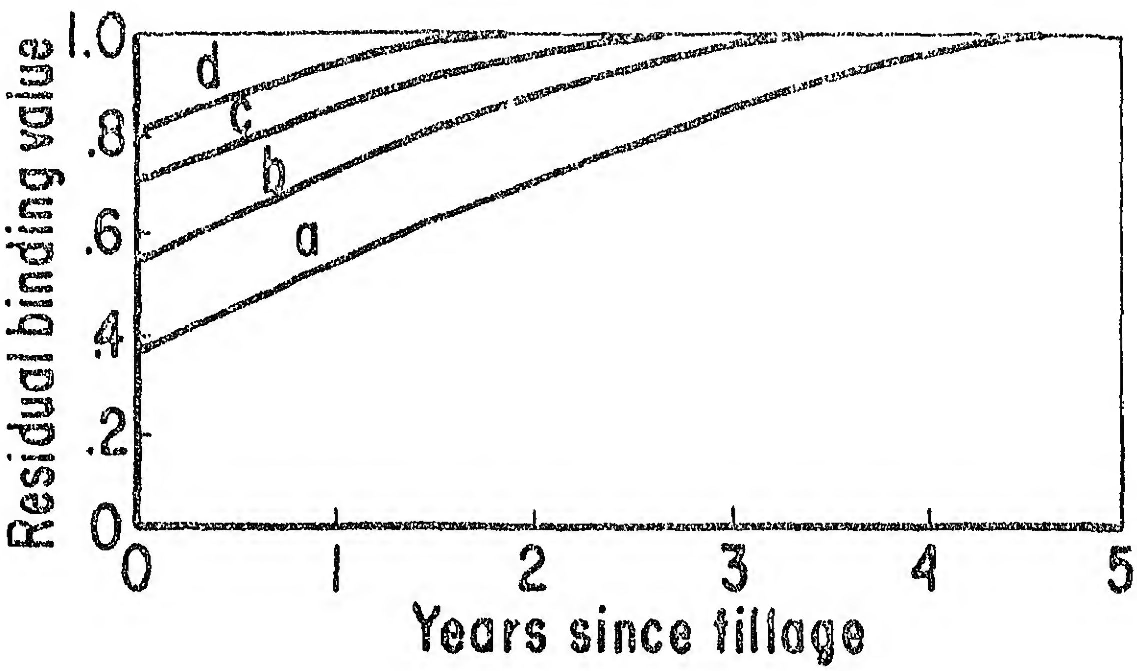

Figure 7.--Residual binding sub-factor.

Legend:

a. - Topsoil has good initial fine root mat, and subsoil has good structure and permeability.

b. - Topsoil has poor initial fine root mat, and subsoil has good structure and permeability.

c. - Topsoil absent with poor initial fine root mat. Subsoil has good structure and permeability.

d. - Topsoil absent with poor initial fine root mat. Subsoil has poor structure and permeability.

Values range from 0 to 1 for forest conditions. A zero means that all detached soil is stored on-site, and a one means no storage. In evaluating on-site depression storage, the observer estimates the proportion of existing on-site erosion that will be trapped in these depressions. To get a depression storage value close to 0.0, the site, usually, must have a small amount of exposed soil and erosion adjacent to depressions that can trap and hold most, if not all, eroded soil.

The observer must be careful not to count depression storage in disked areas. Depression storage in disked areas is accounted for in the contouring sub-factor.

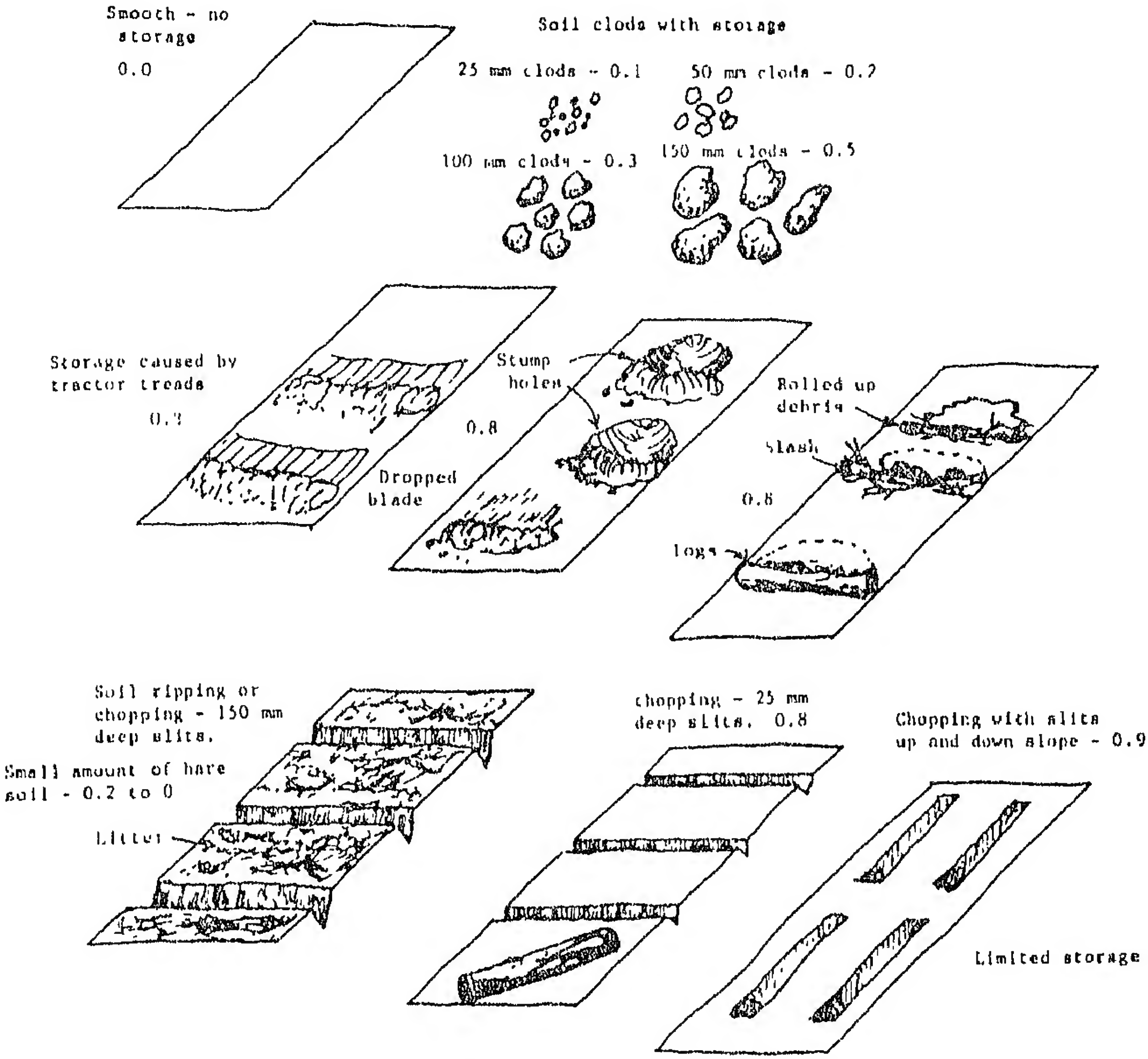

Figure 8.--Sub-factor for on-site depression storage.

STEP SUB-FACTOR

Surface runoff often washes litter and debris downslope until it lodges. This debris forms dams which pond water and collect sediment. When these ponds are full of sediment, they form steps, as illustrated in Figure 9. Steps also form behind roots, clumps of vegetation, and other obstacles and when depressions fill with sediment. Machinery can form steps. For example, the track marks of a tree crusher traveling up a steep slope have the configuration of steps.

Steps reduce slope steepness on areas occupied by steps. Approximately 100 steps were measured throughout the Southeast, and their average slope is 3

percent. The step sub-factor was developed by assuming that the portion of the slope covered by steps acted as short slope segments of 3 percent steepness. Further, runoff was assumed to flow uninterrupted across the steps. Figure 10 was developed by assuming that the steps are small and randomly distributed and by applying Foster and Wischmeier's (1974) irregular slope procedure.

CONTOUR TILLAGE SUB-FACTOR

Disking on the contour generally reduces sheet and rill erosion by reducing runoff amount and velocity in comparison with tillage up and down slope, which is the standard, or base, condition which is assigned 1.0 in the P factor of the USLE (Wischmeier and Smith 1978). Site preparation by disking is similar to agricultural tillage. However, we judged that disking on the contour in forests is usually less effective than contouring from row ridges in farm fields. Ridges from disking do not appear to collect and direct runoff as effectively as crop row ridges. Furthermore, tillage is not repeated on forest land to reform ridges which may have been reduced by erosive rains. Modified USLE P factor values which are increased from standard values (Wischmeier and Smith 1978) for disking are shown in Table 1.

Table 1.--Contour tillage sub-factors.

Percent slope	On contour	Degrees of contour				
		15	30	45	60	90
0-2	0.80	.88	.91	.94	.96	1.00
3-7	0.70	.82	.87	.91	.94	1.00
8-12	0.80	.88	.91	.94	.96	1.00
13-18	0.90	.94	.96	.97	.98	1.00
19+	1.00	1.00	1.00	1.00	1.00	1.00

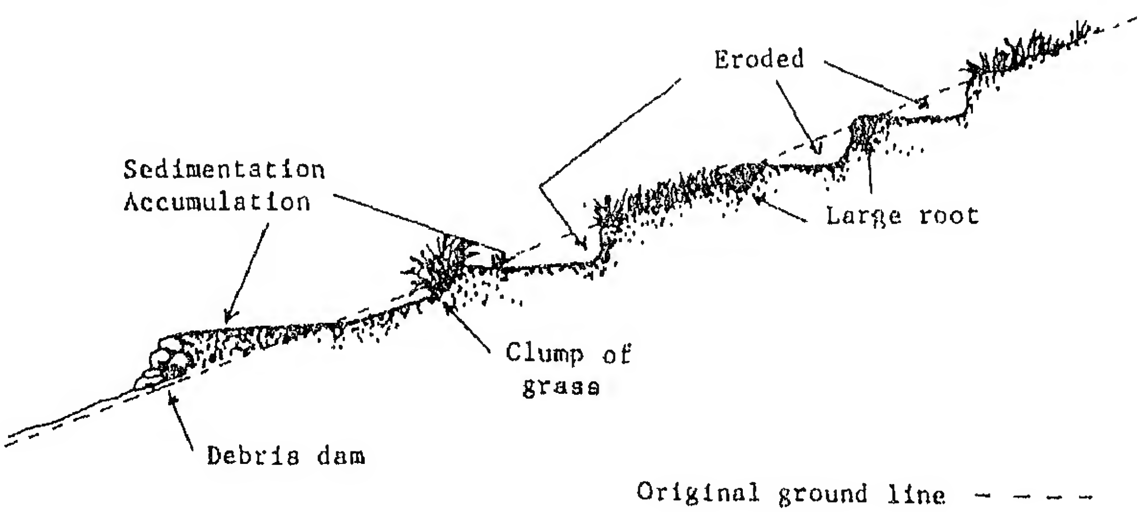

Figure 9.--Step formation.

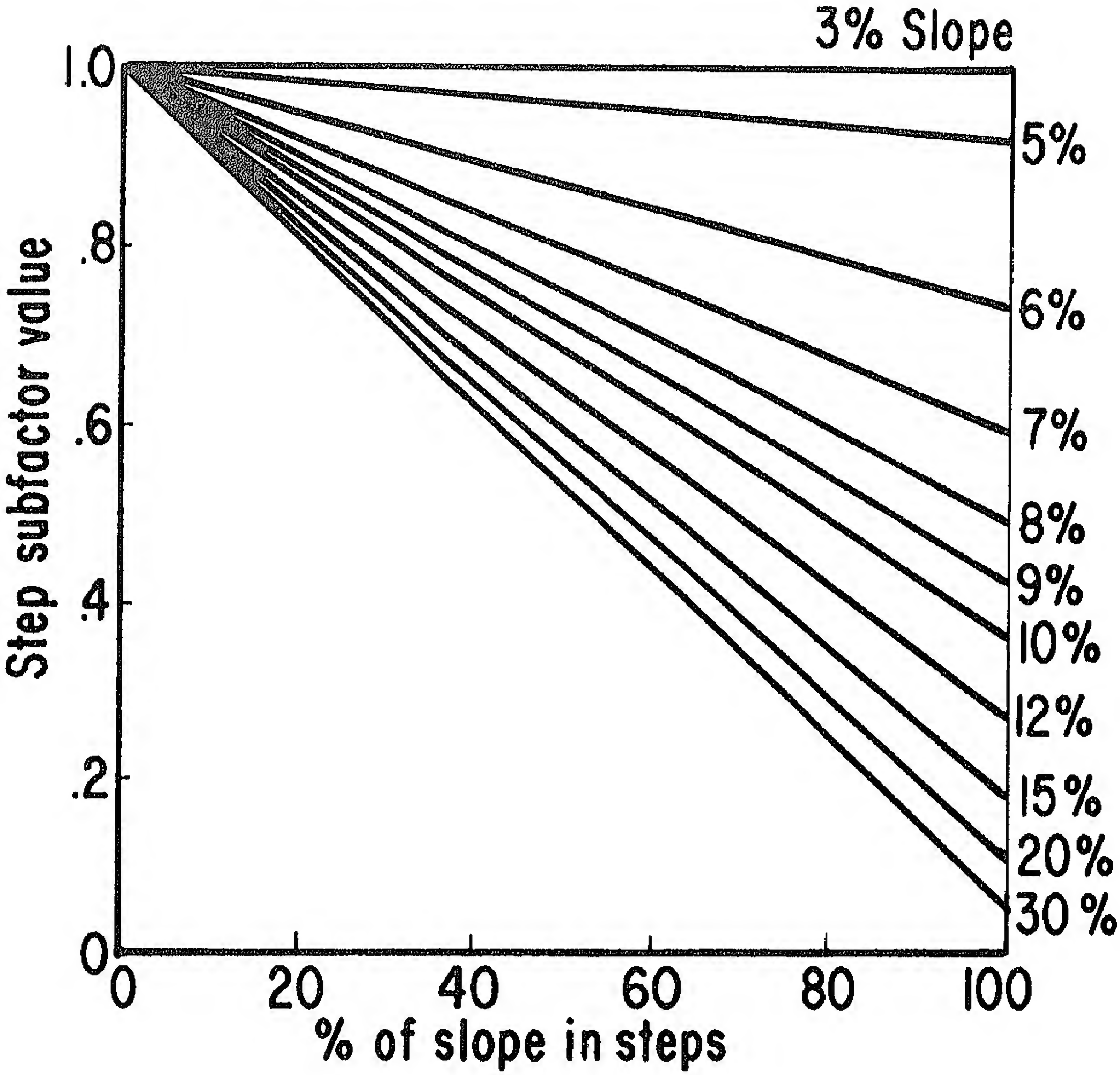

Figure 10.--Sub-factor for steps.

Disking equipment should be operated on the contour, but this is not always practical. This results in ridges and furrows being oriented at an angle to the contour. As the furrows and ridges increasingly deviate from the contour, their effectiveness decreases. As the grade along the furrow increases, transport capacity of runoff in the furrows increases, and the amount of material deposited in the furrow quickly decreases (Foster and Ferreira 1980), which is the basis for the nonlinear increase in P shown in Table 1.

C FACTOR EVALUATION

Values for C are obtained by multiplying the values of the appropriate

sub-factors for a given condition. Sites fall into two disturbance categories (untilled or tilled), and the sub-factors to consider are grouped by category in Table 2. The observer must inspect each site to determine which sub-factors are operating.

Table 2.--Potential sub-factors by disturbance category.

Sub-factor	Disturbance category	
	Tilled	Untilled
Bare soil	X	X
Canopy	X	X
Soil reconsolidation	X	X
High organic content		X
Fine roots	X	X
Residual binding	X	
Depression storage	X	X
Steps	X	X
Contour tillage	X	

The following examples illustrate the use of the sub-factors. The first situation is a disked site that is 6 months old on a 10 perent slope. The site has 70 percent bare soil with canopies over 20 percentof the bare soil. The canopy height is 0.5 meters. The soil has topsoil which contains a good fine root mat, and the subsoil has good permeability and stucture. Vegetation has invaded, and new fine roots occupy 25 percent of the bae soil. Half the new roots are lateral. The disk furrows are 20 degrees off the contour.

The sub-factor values are:

Sub-factor	Sub-factor value	Source of value
Bare soil	0.46	Figure 1
Soil reconsolidation	0.93	Figure 4
Canopy	0.83	Figure 2
Fine roots	0.83	Figure 5
Residual binding	0.44	Figure 7
Contour tillage	0.89	Table 1

The cover-management factor (C) for this disked site becomes:

$$C = (.46)(.93)(.83)(.83)(.44)(.89)$$
$$C = 0.115$$

The second example is an untilled situation - logging on a 10-percent slope. Logging exposed 15 percent bare soil, 30 percent of which has a 1.0 meter high canopy over it. All bare soil has a fine root mat. The topsoil has high organic content and is 75 millimeters thick. Steps occupy 10 percent of the slope. Depression storage was evaluated at 0.9.

The sub-factor values are:

Sub-factor	Sub-factor value	Source of value
Bare soil	0.08	Figure 1
Canopy	0.79	Figure 2
Soil reconsolidation	0.45	Figure 4
High organic content	0.70	Text
Fine roots	0.22	Figure 5
Depression storage	0.90	Figure 8
Steps	0.93	Figure 10

Logging with these sub-factors would produce the following value for C:

$$C = (.08)(.79)(.45)(.7)(.22)(.9)(.93)$$
$$C = (0.004)$$

The C values just determined are for one point in time for a fixed condition. But conditions often change as a disturbance heals and by seasons of the year. If a C factor value is being developed to represent a recovery period or a year, a weighted C factor value must be approximated that reflects changes in sub-factors with time and the variation in rainfall erosivity (R) over the year. Changes in sub-factors can be documented by field observations throughout either the year or the various stages of recovery.

Rainfall erosivity (R) distribution throughout the year are given by Wischmeier and Smith (1978). For a year, a weighted C factor can be approximated by multiplying the seasonal C values times the seasonal R values, summing the products (CR), and dividing by the annual R. This procedure is the same as computing a C factor value for a crop rotation on agricultural land described in Agriculture Handbook 537 (Wischmeier and Smith 1978).

VALIDATION

This procedure was tested using data from forest research watersheds in northern Mississippi, western Tennessee and North Carolina, and research plots in South Carolina. The four plots and 35 watersheds were located in the Southern Coastal Plain, Mississippi Valley Silty Uplands, and Southern Piedmont. The plots were approximately 0.09 to 0.13 ha, and the watersheds ranged between 0.2 and 1.0 ha, averaging 0.5 ha. The forest management conditions, which covered a wide range, included undisturbed, clear-cut, strip cut forests and a variety of site preparation treatments including bedding, chopping, disking, shearing and windrowing, and shearing, windrowing, and seeding with grass.

Observed data included sediment yield, recording raingage charts, soils maps of the watersheds, periodic ground cover surveys, and descriptions of conditions from on-site inspections.[3/] Sediment yield at the plot or watershed

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[3/] The watershed data was provided by Stan Ursic and Jim Douglas, USDA - Forest Service researchers at the Southern and Southeastern Forest Experiment Stations, respectively. The plot data were supplied by forest industry in South Carolina.

outlet is given by:

$$SY = RKLSCP + \text{Channel Erosion} - \text{Deposition} \quad (1)$$

The variables R, K, L, S, C, and P are the standard USLE factors. Their product gives the USLE estimate of soil loss to the end of the slope as defined for the USLE. The USLE does not estimate deposition by overland flow or channel flow, nor gully or stream channel erosion. Gully and stream channel erosion and deposition were estimated from field observations.

Gully and channel erosion were approximated by measuring the length of degradation, by averaging several cross-sectional areas of channels eroded, and estimating the period of erosion. The volume of erosion for a period of time was converted to metric tons per hectare per the study period.

Soil movement was traced to the mouth of the watershed, and where sediment deposits were found, their length, width, and depth were measured. The volume of deposits was converted to tons per hectare per the study period.

Standard procedures (Wischmeier and Smith 1978) were used to estimate R from EI (storm energy times maximum 30-minute intensity) computed from raingage charts for each storm that occurred over a 9- to 12-month period. The value used for R was the sum of the EI's for the study period rather than the average annual R value normally used in the USLE when the equation is used in planning.

The LS factor was estimated using the Foster and Wischmeier (1974) procedure for estimating soil loss from irregular slopes. Soil erodibility factor values for K were obtained from the USDA-Soil Conservation Service, and were assigned to the site based upon soils maps and field inspection. Values for factors C and P were estimated by the procedures already described in this paper.

We estimated sediment yield for each treatment using equation (1) before the measured sediment yield data were supplied to us to avoid biasing the computations. A representative cross-section of the validation data is presented in Table 3 to show the contribution of sheet and rill (USLE), gully and channel erosion, plus what portion was deposited before reaching the mouth of the watersheds.

The measured values are plotted against the estimated values in Figure 11. The points are approximately equally distributed around the line of perfect fit. The regression line for the validation data is close to the line of perfect fit and has R^2 of 0.90. The standard error of the estimate is 1.43, which is 71 percent of the mean measured sediment yield. The validation data were not used to determine or adjust parameter values used to calculate the estimated values. The estimated values are not the result of a fitting of the procedures to the validation data.

Estimates of soil loss were most accurate for high erosion rates, 1.0 metric ton per hectare and greater. The percent error in soil loss estimates with the USLE seems to increase as the estimate decreased. As bare soil decreases to less than 10 percent in forests, its nonuniform distrubition is such that the probability of eroded soil reaching the toe of the slope is highly variable. Intervening litter, storage opportunities, presence or absence of runoff

paths, and continuity of bare soil are variable factors contributing to the error of estimates at low values.

Table 3.--Estimated versus observed sediment yield for selected watersheds.

Condition	Validation data: USLE sheet and rill		Channel or gulley erosion		Deposition		Estimated sediment yield	Observed sediment yield
	--Metric ton/hectare/study period--							
Disked	15.9	+	2.2	–	14.1	=	4.0	2.0
Disked	8.5	+	4.0	–	2.0	=	10.5	6.7
Sheared	4.7	+	0	–	.9	=	3.8	.7
Sheared	12.8	+	1.6	–	7.2	=	7.2	12.1
Disked [1/]	22.2	+	0	–	0	=	22.2	22.2
Disked [1/]	11.4	+	0	–	0	=	11.4	10.1
Disk and grass [1/]	11.6	+	0	–	0	=	11.6	8.5
Chop [1/]	1.3	+	0	–	0	=	1.3	1.6
Chop	.7	+	0	–	0	=	.7	2.2
Shear	1.1	+	0	–	0	=	1.1	2.2
Clear cut	.7	+	0	–	0	=	.7	.9
Clear cut	.13	+	0	–	0	=	.13	.013
Strip cut	.2	+	0	–	0	=	.2	.04
Strip cut	.3	+	0	–	0	=	.3	.1
Disk and grass	1.8	+	0	–	0	=	1.8	.33
Disk and grass	2.5	+	0	–	2.3	=	.2	.1

[1/] Plots where eroded soil was trapped at toe of slope.

The field data for this validation were subject to error. Errors could be large in the estimates of deposition and channel erosion from field observations. Also, the time period only included 9 to 12 months of precipitation. At least 10 years of data were preferred to obtain good average annual soil loss estimates. However, forest disturbances in the Southeast heal rapidly, which prevents easily studying the same condition year after year on the same plot. Also, there could have been error in the estimates of the soil erodibility factor K, which were estimated from soil surveys of the watersheds. Although better data would have been desirable, as far as we know, none exist. Good quality data to develop and validate the USLE for forestry conditions remains an important need.

A new procedure for estimating the values for the USLE cover-management factor C was developed by modifying and extending Wischmeier's sub-factor approach (1973, 1975, 1979) which he developed for undisturbed areas and cropland. The basic concepts of the new procedure are general and should apply to

many areas of the United States as Wischmeier's (1975) sub-factor approa
undisturbed area is applied nationally.

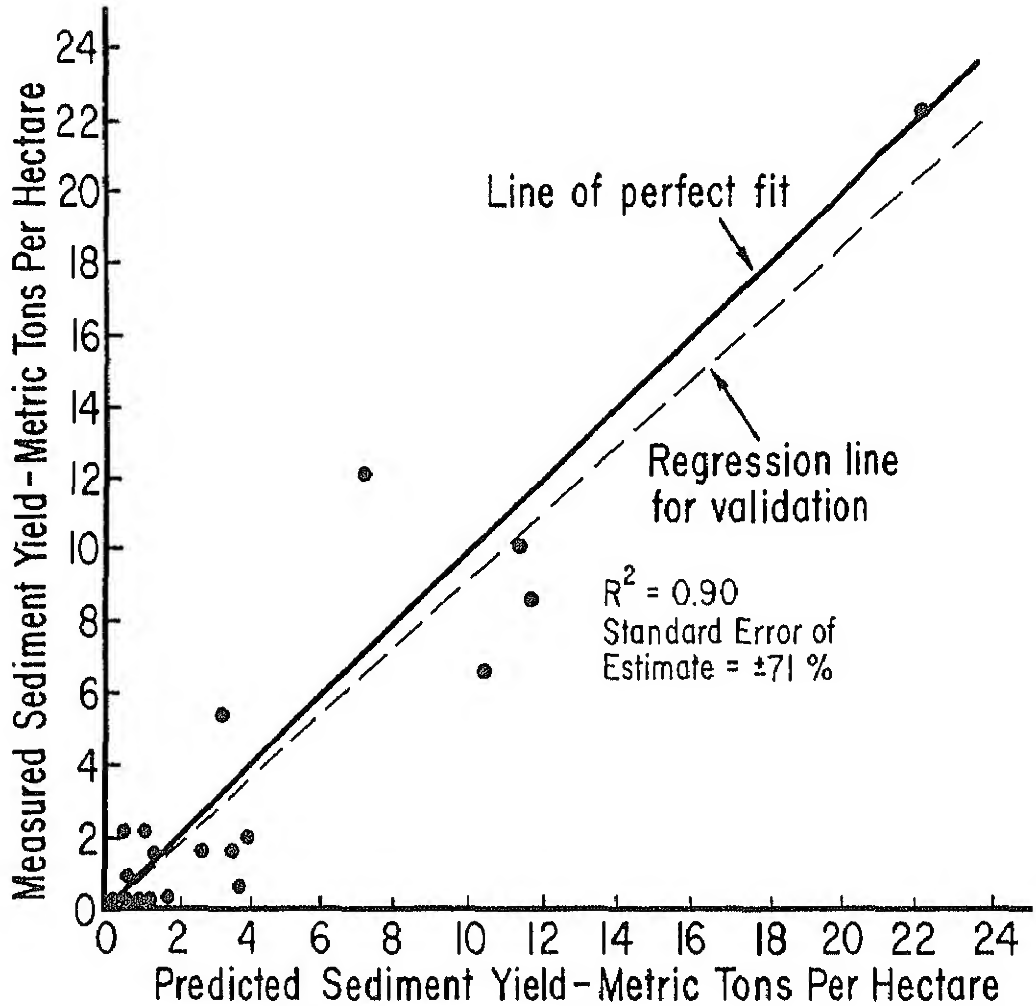

Figure 11.--Validation data for forest conditions.

CONCLUSIONS

Results of the validation, using data from 39 research watersheds Southeast, suggested that the procedure gives reasonable values for the cover-management factor C for forest conditions. This procedure incorp many of the factors that affect sheet and rill erosion on forest land an vides a means for evaluating C for a broad range of conditions that cou be accomplished with a classification system. Furthermore, the results validation suggest that the USLE can be used to estimate sheet and rill e for forest conditions where the equation appropriately applies. The pro for estimating C is recommended as the basis for a replacement for Tab and 12 in Agricultural Handbook 537 (Wischmeier and Smith 1978).

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SURFACE EROSION FROM FOREST ROADS--
A PROPOSED RESEARCH PROGRAM USING SIMULATED RAINFALL

Edward R. Burroughs, Jr., and Eric S. Sundberg[1/]

INTRODUCTION

Forest road construction for timber harvest and forest access is a continuing activity throughout the United States. The Forest Service alone constructs over 10,000 miles of forest roads each year, with a high percentage surfaced with native soil or crushed rock. Road and trail construction for the Forest Service in fiscal year 1981 will cost over $500 million.

These forest roads can contribute large volumes of sediment to streams during and immediately after road construction. The surface erosion rate from roaded watersheds can be 220 times (Megahan and Kidd 1972) to 250 times (Fredricksen 1970) the erosion rate from adjacent and undisturbed watersheds. This erosion rate typically declines sharply with time after construction (Megahan 1974).

Forest roads are often adjacent to streams whose water quality is high and must remain so to protect municipal water supplies, recreation values, or important fish habitat. Many times the choice between alternative routes for forest roads or the choice between surfacing treatments depends upon estimates of the amount of sediment that a planned forest road will produce. Intelligent planning of forest resource management with minimal environmental impact requires a method to estimate surface erosion from forest roads for given topographic, geologic, and climatic conditions.

Tests of a predictive model for runoff and sediment yield from surface mine roads have been completed satisfactorily. In our opinion, the ROad SEDiment (ROSED) model developed by Simons et al. (1977) provides a basic model for use on forest roads.

[1/]Intermountain Forest and Range Experiment Station, U.S. Dept. of Agriculture, Forest Service, Forestry Sciences Laboratory, P.O. Box 1376, Bozeman, Mont. 59715; and Forestry Sciences Laboratory, 1221 So. Main St., Moscow, Idaho 83843, respectively.

PROPOSED RESEARCH APPROACH

Our general research approach will use a 0.1 acre (0.04 ha) rainfall simulator to apply a measured amount of rainfall to selected sections of forest roads to isolate the effect of road and materials characteristics on runoff and erosion. Instrumented road sections in two experimental watersheds in northern and central Idaho (Horse Creek and Silver Creek) are dedicated to measurement of runoff and sediment yield from snowmelt and natural rainstorms. Data from rainfall simulator tests will allow us to bridge the gap from these instrumented road sections in the Idaho Batholith to forest roads with similar site characteristics.

Earlier work with simulated rainfall on surface mine roads indicated that intensive study is needed to make the ROSED model into an operational planning tool for forest land managers (Johnston et al. 1980; Sundberg et al. 1981). The version of ROSED currently available cannot be used for planning purposes because it is too complex and its model parameters are not well enough defined.

One of the most important planned studies will be developing algorithms to estimate the infiltration and saturated hydraulic conductivity of the road surface and ditch using such characteristics as density, particle size gradation, and type and amount of clay. A small overhead sprinkler type of infiltrometer, as designed by Meeuwig (1971) and modified by Malekuti and Gifford (1978), may be used in the field to develop first approximations for these algorithms prior to large scale rainfall simulator tests.

A second area of research will be concerned with overland flow resistance, a parameter that is not well defined in ROSED where a value for resistance must be selected from a range of tabular values. Preliminary tests using dye to measure overland flow velocity on surface mine roads show that the overland flow resistance parameter may vary from -20 to +25 percent away from a selected constant value. Detailed studies are needed to relate overland flow velocity to measurable site characteristics such as particle size distribution of surface materials, slope gradient, and rainfall intensity.

Soil detachment by simulated rainfall was assumed to be negligible in our analysis of field data from surface mine roads, and the model parameter was set at a low value. More work needs to be done on measurements of soil detachment to accurately represent its effect on sediment yield for both simulated rainfall and natural rainstorms.

The ROSED model requires a separate runoff detachment coefficient, D_f, to be determined for each overland flow unit and ditch segment. An empirical procedure to calculate this parameter was suggested by Simons et al. (1979):

$$D_f = \frac{K(D_{50})^2}{0.63}$$

where: D_f = soil detachment coefficient for runoff

K = soil erodibility index from the Universal Soil Loss Equation (Wischmeier et al. 1971)

D_{50} = median soil particle size in millimeters.

More data are needed to validate this approach.

Procedures to estimate model parameters need to be tested over a wide range of soils and road-surfacing materials. Work is planned to relate site factors such as loose surface soils, percent of the soil in certain critical particle sizes, and other site characteristics to model parameters. Studies also will be designed to monitor how road surface and ditch characteristics are changed by heavy truck traffic and normal road maintenance. Measurements of runoff and sediment yield with various road characteristics will be used to test the ability of the ROSED model to represent the changing performance of forest roads with time and use.

Two needed modifications of the ROSED model are already identified: the addition of a snowmelt subroutine, and the use of ditch cross-sections other than the triangular shape used in ROSED. Several snowmelt models already exist that could be attached to ROSED. The obvious approach would be to use the snowmelt model to provide input to ROSED, suppress the rainfall detachment process, and rely on soil detachment by runoff to produce sediment. Comparisons between sediment yield from instrumented road sections during snowmelt and predicted sedimentgraphs can be used to test this modification to ROSED. We hope to use portions of the CREAMS channel erosion and sedimentation programs to improve the functioning of ROSED for road ditches with flat-bottomed cross-sections. We will also evaluate the CREAMS model for use on overland flow sections of roads built with cohesive natural soil surfaces.

Another major area of concern is the standardization of field data collection techniques and laboratory analysis methods. We want to coordinate our sampling methods with input needed by model developers so that the data can have maximum utility for model development and testing. Our particular emphasis is on soil gradation analysis techniques, sediment sampling and analysis, soil water content and soil density measurements, and watershed survey techniques to determine surface runoff flow patterns.

SUMMARY

We feel that it is beyond our resources to become involved in extensive model development or modification. Our objectives are to test existing model parameters with easily measured site characteristics. We would like to maintain close contact with other agencies or projects with similar objectives to test the latest advances in the state-of-the-art of surface erosion modeling.

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SOIL EROSION TOLERANCE VALUES

W.C. Moldenhauer, SEA-AR soil scientist 1/

INTRODUCTION

The term "soil loss tolerance" denotes the maximum amount of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely, according to Wischmeier and Smith (1978). They note that soil loss tolerances ranging from 2 to 5 t/a/yr for soils of the U.S. were derived by soil scientists, agronomists, geologists, soil conservationists and Federal and State research leaders at six regional workshops in 1961 and 1962. Factors used in determining these tolerance values were undoubtedly those developed at a USDA Joint Conference on Slope Practice held in 1956 at Purdue University, Lafayette, Indiana (USDA-ARS and SCS, 1956). These factors are:

a. Maintenance of an adequate soil depth for crop production
b. Value of nutrients lost
c. Maintenance of water control structures (e.g. open ditches, ponds, reservoirs, terrace channels), and the control of flood plain sedimentation
d. Prevention of gullies
e. Crop yield reduction (per inch of topsoil lost)
f. Water losses
g. Seeding losses

Although soil loss tolerance could be lower, 5 tons per acre per year was chosen as an upper limit. Although the use of soil tolerance (T factor) with the Universal Soil Loss Equation began in the early 60's, the concept of soil loss tolerance was considered much earlier. These early attempts are discussed by McCormack et al. (1979).

1/ Contribution of USDA-Science and Education Administration-Agricultural Research, Lafayette, Indiana in cooperation with the Purdue University Agricultural Experiment Station, West Lafayette, Indiana. Purdue Journal No. 8530.

CURRENT CRITERIA

Current criteria cited by McCormack and Young (1980) for assigning T values are:

a. An adequate rooting depth must be maintained for plant growth. Soils impervious B horizons are given lower T values than those with deep permeable subsoils.
b. Soils that have significant yield reductions, if the surface layer is removed by erosion, are given lower T values than soils that have only minor yield reductions if the surface is removed.

According to McCormack and Young (1980) a maximum T value of 5 tons per acre has been selected for the following reasons:

1. Soil losses in excess of 5 t/a/yr affect the maintenance, cost and effectiveness of water control structures that can be damaged by sediment.
2. Excessive sheet erosion is accompanied by gully formation in many places.
3. Loss of plant nutrients is considered excessive.
4. On most soils, conservation practices can keep soil losses below 5 t/a/yr.

They also point out that, in evaluating the long-term impact of soil erosion, it is necessary to make assumptions about rates of soil formation, most of which have not been proven by research.

LOSS OF SOIL NUTRIENTS AND ROOT ZONE DEPTH

In the USDA-ARS and SCS conference (1956) soil nutrients were valued at $2.00 per ton of soil loss and it was assumed that plant nutrient losses of more than $10.00 per acre per year might be excessive for any farmer. An update of these figures by McCormack and Young (1980) set the average value of N, P, and K lost in one ton of soil at $6.00. Loss at the 5 ton per acre limit would then be $30.00. They also cite as the most important reason for the 5 ton per acre limit the assumption that soil A horizon can form at the rate of 1 inch in 30 years. This is equivalent to a rate of 5 tons per acre per year of soil formation. They point out that formation rates of the A horizon of medium to course textured soils may be more rapid than this, and on finer textured soils may be much slower.

Knowing the rate of root-zone formation is vital to predicting the long-term effects of ersoion. Limiting the annual soil loss to 5 tons per acre might maintain an A horizon thickness for many centuries, but the total root zone would become thinner according to McCormack and Young (1980).

McCormack et al. (1979) point out that we have not adequately justified a maximum of 5 t/a/yr for soil loss tolerance on our thickest, most productive soils or the eventual destruction, in 2 or 3 thousand years, of their productivity. Whereas early work focused on the impacts of the loss of the A horizon, future work must concentrate on the effect of loss of the whole soil.

REDUCTION IN PRODUCTIVITY

According to McCormack et al. (1979), soil scientists must learn more about the irreversibility of the impacts of soil erosion (as discussed by Ciriacy-Wantrup (1952). In particular, they must determine the rate at which the productivity of eroded soils can be restored and the kind of management required to restore it.

McCormack et al. (1979) point out that if average corn yields are reduced by 3 bu/a/yr for each inch of soil loss, over a period of 100 years a productivity loss of 300 bu/a would be sustained for each inch of topsoil lost.

Viewed from the perspective of 100 years from now with erosion at the present rate, annual net erosion loss (counterbalanced against soil formation) would have a value of $7 billion (McCormack and Larson, 1980). Annual loss of nutrients currently ($6.80 per metric ton) is worth $13 billion not counting the contribution to water pollution. Dredging harbors is costing $120 million annually as a result of cropland erosion. Annual loss of reservoir capacity is valued at $2.14 billion.

From McCormack et al. (1979) conservation objectives could be based on the need for production from land susceptible to erosion as determined by political and social leaders. Where the objectives would result in erosion at rates greater than the soil loss tolerance, the scientist must explain the long-term impacts on productivity.

Future generations will benefit from erosion control but are not here now to pay for this benefit (Seitz and Hewitt, 1979). On the other hand, if we fail to control erosion in our time, future generations will be unable to avoid paying for that failure. The farmer may, at little or no economic risk, subject his soil to erosion levels that are excessive even during his own generation (Hardin, 1968).

DISCUSSION

Even though some suppositions used to set soil loss tolerance values are not scientifically well supported (e.g. rate of soil formation and damage to deep fertile soils as the rooting depth is reduced), the framework is useful for decision making on tolerance limits and the ramifications of setting those limits. Soil loss tolerance decisions might be made differently if scientists and technical people turn this decision making over to farmers, society leaders and public policy makers who would probably use different sets of criteria than have been employed by scientists and conservation technologists.

An ethic of stewardship might be adopted as suggested by McCormack and coworkers. While this is noble and desirable, it probably won't happen. The real world is too pragmatic, and success or failure of his enterprise may hinge on what an individual farmer does about conservation. Conservation is not high on the list of a farmer's priorities when he is on the verge of bankruptcy. On the other hand, if society insists that farmers practice conservation, society

could be expected to share in the social and financial costs of getting it done.

There are valid reasons to control soil erosion at a certain level. The level may, however, be quite different depending on the criteria used to set the limit and the special interests of the individuals concerned with erosion or paying for its control.

The following are some criteria for tolerance limits and the level of interest that might be found in the various involved groups. We must realize that many farmers and scientists are part of concerned society. These speculations consider the farmer in the narrow sense of making a living in the short term against near overwhelming odds.

CRITERIA	SCIENTIST	INTEREST OF FARMER	CONCERNED SOCIETY
Affect on maintenance, cost and effectiveness of water control structures that can be damaged by sediment	high	high	high
Affect on gully formation	high	high	high
Loss of plant nutrients	high	moderate	high
Possibility of achieving	moderate	slight	moderate
Balance against soil formation	high	slight	high
Water polution	high	moderate	high
Long term crop yield reduction	high	low	high
Short term crop yield reduction	high	high	high

Scientists and concerned society are most interested in preventing gradual damages as well as sudden catastrophic damages. The farmer may be more interested in damages that interfere with his farming operations or that cost him extra money to produce crops. He is less interested in balancing erosion against soil formation, but as far as conservation is concerned is very much interested in whether he can achieve tolerable limits without going bankrupt.

If we insist on tolerance limits without compromise, we must set these limits at the lowest level needed to achieve the goals scientists, farmers and society agree to. The difficult part is deciding, in most cases, what these levels should be. Larson (1981) suggests a T_1 value based on maintenance of long term productivity as determined by scientists. A second value -- T_2 -- would reflect broader social goals including nonpoint water pollution control. Criteria for these two values would be much different, since one would be determined by long-term damage to the soil and the other by off-site damage from soil erosion. From the standpoint of the long-term interest of society (society protecting itself) the smaller of the two T values should always be used. This may not, however, be the choice of societal decision makers.

SUMMARY AND CONCLUSIONS

The concept of soil loss tolerance limits is well justified, both from the standpoint of protecting our soil resource and of protecting water quality and the capacity of our reservoirs, rivers and harbors. To date, tolerance limits have been set only to protect the productivity of the soil resource. While the quantitative basis for the presently used limits has been questioned, there are certainly logical bases for them. In most cases, they have worked well in farm planning and in protecting the soil from irreparable damage.

Before more effort is expended in quantifying T_1 (Larson, 1981), the T_2 limits (Larson, 1981) should be set. Unfortunately, this task is much more complex than setting the T_1 limits because of the nature of the data required and the complexity of the model required to analyze the impact of erosion from these data. Also, the required input of nonscientists is diffucult to obtain because of the background of knowledge and understanding required to make these decisions. Thus, setting the T_2 limits will require a major effort which should be begun immediately.

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"T" Factors on Rangelands
Rangeland Soil Erosion Workshop
Tucson, Arizona

Panel Discussion - M.B. Rollins
March 5, 1981

It is common for cropland soils to tolerate erosion of up to five tons per acre per year. But cropland soils are usually deep soils in higher rainfall areas or are irrigated and therefore grow large amounts of vegetation. Such soils form topsoil rapidly, especially since plant material is plowed back into the soil. For these reasons, cropland soils may tolerate up to five tons of soil erosion per year and maintain productivity.

But rangeland soils are different. Rangeland soils are usually thinner than cultivated cropland, found in a drier climate, and plant material is not plowed back into the soil. Therefore, rangeland soils cannot tolerate the seemingly high erosion of cultivated soils and still maintain productivity.

This low tolerance becomes more apparent when soil erosion is examined by depth and time. For example, an acre inch of topsoil weighs about 166 tons.

If a soil were to lose five tons per year from erosion, it would take only 33 years to lose an inch of topsoil. This is far too short a time for rangeland soils to regenerate an inch of topsoil and maintain productivity.

Even at three tons of loss per year, an inch of soil would be lost in about 50 years. This is still too short a time for most range soils to regenerate.

At two tons of loss per year, an inch of loss time is extended to 83 years.

And at one ton of loss per year, it would take 166 years to lose an inch of topsoil. This rate might be a little closer to reality for rangeland soils if conditions are favorable for soil regeneration.

For example, let's examine the rate of soil development for some Montana rangeland soils, which are some of the best soils found on public lands managed by BLM. A Phillips loam (a Borollic paleargid) is a native grassland soil found on the glaciated plains of eastern Montana, in the 10-14 inch rainfall zone. A typical Phillips has developed seven inches of A horizon in about 12,000 years (since the last glacial period). This amounts to about 0.6 of an inch of A horizon developed every 1,000 years.

The Phillips soil has one of the thickest A horizons of Montana rangeland soils. Most Montana rangeland soils have about four inches of A horizon. This would be about .33 of an inch developed every 1,000 years, if we assume the A horizons were developed during the last 12,000 years (for the glacial soils).

Therefore, considering rate of soil development (even on the best of our rangeland soils), it is obvious that soil-loss tolerances associated with cropland soils are far too high for native rangeland soils. Perhaps we need to think in terms of less than one ton of soil erosion a year to maintain soil productivity on native rangeland soils.

APPLICATION OF THE SOIL LOSS TOLERANCE CONCEPT TO RANGELANDS

J. Ross Wight, USDA-SEA-AR range scientist

and Collis J. Lovely, BLM hydrologist[1/]

Soil loss tolerance (T-value) is defined as the amount of annual soil loss that can be sustained without reducing crop production. It is usually determined on the basis of soil depth, root zone thickness, and some knowledge of soil formation rates. In addition, the T-value concept assumes that: 1) soil depths exceed rooting depths; 2) soil loss can occur without significantly reducing productivity, as long as remaining soil depth is equal to or greater than the original rooting depth; and 3) maintained site production values are high enough to permit periodic mechanical restoration. For croplands, these assumptions can usually be satisfied, and the T-value concept provides a useful management guide. For rangelands, however, these criteria and assumptions are rarely satisfied, and the T-value concept, as defined above, is of questionable value and applicability.

Rangelands, which are often characterized by steep slopes, shallow soil mantles, and/or sparse cover are inherently more fragile than croplands. In the arid and semiarid rangeland climates, soils form slowly. Even small increases in soil losses can initiate accelerated soil erosion trends, as soil losses are accompanied by reduced production of protective vegetation. This is especially true on sites where shallow soil depth is already a major plant growth limiting factor. In such cases, any net soil loss reduces productivity. Because of low per unit area values, intensive mechanical restoration of deteriorated rangelands is generally not feasible.

For T-values to have management application, at least three criteria should be satisfied: 1) valid T-values can be determined for the soils or sites in question; 2) soil loss can be determined with reasonable accuracy; and 3) relationships between soil loss and management can be quantified. Recognizing a properly managed range site in good-to-excellent range condition class as being in equilibrium with its environment and at or near a maximum level of sustained productivity, the T-value for such a site would logically be equal to the ongoing annual soil loss. On sites in deteriorated conditions,

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[1/] Northwest Watershed Research Center, USDA-SEA-AR, Suite 116, 1175 South Orchard, Boise, Idaho 83705, and Hydrology and Water Resources, Division of Rangeland Management, USDI-BLM, Washington D.C. 20240. In cooperation with the Agricultural Experiment Station, University of Idaho, Moscow, Idaho 83843.

T-values, somewhat less than the ongoing annual soil loss, could be established as a means of restoring the sites to a production level consistent with their environment. However, until actual soil loss from rangelands can be determined, such statements regarding T-values for rangelands are somewhat philosophical and have little or no management application.

The use of predictive equations, such as the Universal Soil Loss Equation (USLE), has not been effective for determining soil loss from rangelands, Blackburn (1980); Renard (1980); and Trieste and Gifford (1980). The large errors associated with predictive equations can be hazardous when applied to the management of fragile rangelands. In the application of the USLE to rangelands, the cover factor is about the only management sensitive factor, Johnson et al. (1980), and changes in calculated soil loss simply reflect changes in plant cover. If the changes in soil loss for specific range sites are almost totally dependent upon changes in cover, it seems more practical to determine cover for the range sites in good-to-excellent condition, and manage for that level of cover, rather than running the cover factor through a predictive equation, and managing on the basis of predicted soil loss.

In regards to rangelands, we are currently unable to determine ongoing soil losses or establish soil loss tolerances with reasonable accuracy. The relationships between soil loss and rangeland management are not well defined. Under these conditions, T-values appear to have little management implication. As stated by Wight and Siddoway (1981), "T-values for rangelands may be a concept with only an idealistic application." However, as methods are developed for determining soil loss, soil loss-management relationships, and T-values that incorporate the unique features of rangelands, the T-value concept will find useful application in rangeland management.

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PLANNING RESEARCH TO EVALUATE THE EFFECT OF SOIL EROSION ON SOIL PRODUCTIVITY

J. R. Williams, SEA hydraulic engineer

INTRODUCTION

Accurate estimates of future soil productivity are essential in agricultural decision making and planning from the field scale to the national level. Soil productivity is defined as the capacity of a soil in its normal environment for producing a specified plant or sequence of plants under a specified management system. Productivity emphasizes the capacity of soil to produce crops and should be expressed in terms of yields. Soil erosion depletes soil productivity, but the relationship between erosion and productivity is not well defined. Until the relationship is adequately developed, selecting management strategies to maximize long-term crop production will be impossible. Poor decisions can easily result in serious damage to soil resources--productivity may approach zero in many severely eroded areas of the U.S. Conversely, poor decisions can result in under utilization of soil resources and loss of income to the producer and food and fiber supply to the consumer.

CHARACTERISTICS OF THE PROBLEM

One of the most dangerous characteristics of the soil erosion-productivity problem is difficulty of detection. Erosion reduces productivity so slowly that the reduction may not be recognized until land is no longer economically suitable for growing crops. Futhermore, improved technology often masks the lowering of soil productivity. For example, some eroded soils respond well to heavy fertilizer applications.

The difficulty of detecting productivity losses is compounded by the nonlinear nature of the erosion processes. Erosion generally increases future runoff because of reduced infiltration rates. Increased runoff reduces available soil water and thus plant growth. Of course less plant growth means less residue. Reduced vegetation and residue provide less cover and thus increase erosion. Because water erosion is strongly related to runoff, the increased runoff also leads to an increase in erosion. Thus the process advances exponentially--reversal may quickly become economically infeasible if the process is not detected and controlled properly.

Another characteristic of the erosion-productivity problem is the difficulty of restoring the productivity of severely eroded soils. Restoration is generally difficult and costly because subsoil conditions often inhibit crop growth. These conditions include poor aeration; low organic matter, exchangeable or

soluble nutrients, and calcium carbonate; and high soluble aluminum, gravel, and density (strength). Although productivity can be partly restored by adding organic material and fertilizer, such additions may not be economically feasible. For example, eroded rangeland is particularly difficult to restore because fertilization is usually not economically feasible in low rainfall areas (See Figure 1).

WAYS EROSION REDUCES PRODUCTIVITY

Probably the most important way that erosion reduces productivity is through loss of plant-available soil water capacity. Lower soil water capacity subjects crops to more frequent and severe water stress. Plant-available soil water may be decreased by reducing the root zone depth or by changing the water holding characteristics of the root zone. Erosion reduces the root zone depth if subsoils are toxic to roots or have high strength or poor aeration that retards root growth. The water-holding characteristics of the root zone are almost always changed when topsoil is removed (usually topsoil has higher plant-available water capacity than subsoil).

A second way that erosion reduces productivity is by contributing to plant-nutrient losses. Eroded soil particles transport adsorbed nutrients from fields into streams and lakes. Since subsoils generally contain less plant nutrients than topsoils, additional fertilizer is required to maintain crop production. Although fertilizer can partially compensate for low crop yields from subsoils, production cost is increased. The problem is further compounded if the subsoil contains more clay than the topsoil (a common occurrence), because clay tends to quickly transform applied phosphorus into forms not readily available to plants.

A third way that erosion reduces productivity is by degrading soil structure. Degradation of soil structure increases soil erodibility, surface sealing, and crusting, and leads to poorer seedbeds. Surface sealing and crusting decreases seedling emergence and infiltration rates. Reduced infiltration rates provide less opportunity for soil water storage.

A fourth way that erosion reduces productivity is through nonuniform removal of soil within a field. Erosion does not occur uniformly across a field mainly because of the runoff flow network and nonuniform topography. Selecting a management strategy to maximize production is nearly impossible in fields with various degrees of erosion because fields are usually farmed as units. When fields are farmed as units, fertilizer is normally applied uniforml over the field. If erosion is nonuniform, the application rate is more appropriate for some areas than others (optimal production is impossible for all areas). The effect on herbicide use is similar. Because herbicides interact with soils, their performance varies with soil organic matter content, pH, and cation exchange capacity. In a nonuniformly eroded field one rate of herbicide application may kill weeds and damage the crop in one part of the field but may not effectively control the weeds in another part of the field.

Nonuniform erosion also affects timing of farming operations. Proper timing, especially of planting, has an important impact on productivity. Frequently erosion-exposed clay subsoils are too wet when the rest of the field

is suitable for farming operations. The farmer must either avoid these clay areas or wait until they are dry enough to permit tillage. Nonuniform erosion also causes variable tillage effectiveness and inconsistent seedbeds that produce poor stands and deviations in emergence dates.

Energy requirements are also greater for nonuniformly eroded fields. Tilling a subsoil usually requires more power than tilling a topsoil and additional energy is needed for filling and smoothing gullies. If gullies are neglected, row lengths are shortened, which reduces farming efficiency.

CURRENT RESEARCH

Although a limited amount of research has been devoted to the soil erosion-soil productivity problem specifically, considerable effort has been concentrated on most of the important processes involved. Current research that is most closely related to the problem includes tillage, crop growth, nutrient cycling, nonpoint source pollution, water erosion-sedimentation, wind erosion, and hydrology. Besides this research on various processes, there are two Science and Education Administration-Agricultural Research (SEA-AR) national teams developing mathematical models for application to two closely related problems (crop growth and nonpoint source pollution). However, the necessary components (hydrology, water erosion-sedimentation, wind erosion, nutrient cycling, crop growth, tillage, animal uptake, etc.) have not been linked to form a model structure appropriate for studying the erosion-productivity problem.

RCA NEEDS

In response to PL 95-192, the Soil and Water Resources Conservation Act of 1977 (RCA), the Secretary of Agriculture was requested to make an appraisal of soil, water, and related resources and their conservation, and to make informed long-range policy decisions regarding the use and protection of these resources. With the development of plans to implement the RCA, it became obvious that there was no reliable method for estimating the cost of erosion or the benefits from erosion research and control. In an effort to overcome this deficiency, Hagen and Dyke (1980) developed an empirical crop yield-soil loss relationship for use in the RCA appraisal process. The yield-soil loss regression equations provided information to a linear programming model used for determining optimal national management policies. Hagen and Dyke's effort was particularly significant because it was the first attempt at developing a nationally applicable yield-soil loss relationship. In many areas of the country, however, the results differed widely from independent experimental observations not used in developing the equations. Thus, a workshop was held on February 26-28, 1980, at Washington, D.C., to discuss ways of improving the yield-soil loss relationship. Representatives from the Economics and Statistics Service (ESS) (developers of the empirical relationship) described their approach to representatives from the Soil Conservation Service (SCS) and SEA. The workshop provided an excellent audience to critique the ESS yield-soil loss prediction methodology. Also, research results, current research on the problem, and future approaches were discussed.

From these discussions it was apparent that the erosion-productivity problem deserves special research attention. Thus, the National Soil Erosion-Soil Productivity Research Planning Committee[1/] was appointed to develop a suitable soil erosion-productivity relationship. The objectives of the committee's work were to:

A. Determine what is known about the problem.

   1. Define the problem.
   2. Identify research accomplishments.
   3. Identify current research efforts.

B. Determine what additional knowledge is needed.

C. Develop a research approach for solving the problem.

In response to the assignment, the committee developed a comprehensive state-of-the-art paper "The Influence of Soil Erosion on Soil Productivity." The report requested by the Administrator of SEA-AR and the Director of SEA provides guidelines for future research. It assessed the present knowledge of the effect of erosion on productivity, the research currently underway, research needed to fill the gaps, and a FY-82 budget item for continued effort in this area. As a result of the report, the Administrator of SEA-AR appointed a Steering Committee[2/] to develop plans for expanding work on erosion-productivity relationships. The report was modified and published (National Soil Erosion-Soil Productivity Research Planning Committee, 1981). In addition to the major topics, it includes an extensive list of references to related publications.

The Steering Committee met at Beltsville, MD, in December, 1980, to develop plans for a major effort in erosion-productivity research. The committee decided that the research could be accomplished most effectively through a national team effort concentrating on four specific topics: (1) Mathematical modeling; (2) Field experiments; (3) Erosion prediction; and (4) Conservation tillage. The Steering Committee also discussed the selection of a coordinator for the research and made recommendations to the National Program Staff. SEA-AR's National Program Staff, acting on the Steering Committee's advice, selected K. G. Renard as Coordinator.

1/Committee Members

J. R. Williams, Chairman	L. Lyles	L. D. Meyer	G. Darby
R. R. Allmaras	W. C. Moldenhauer	W. J. Rawls	R. Daniels
K. G. Renard	G. W. Langdale		R. Magleby

2/Committee Members

K. G. Renard	W. E. Larson	L. D. Meyer
F. H. Siddoway	B. A. Stewart	J. R. Williams

FUTURE RESEARCH

Mathematical modeling and field experiments to support the models must be initiated to study the soil erosion-soil productivity relationship. Objectives of the research include: (a) Developing a physically based model capable of realistically simulating the processes that affect soil erosion and soil productivity; (b) applying the model to many areas throughout the U.S. to adequately define the erosion-productivity relationship; and (c) providing model outputs necessary for economic analyses concerning the cost of soil loss. Figure 2 is a diagram of some of the important elements to be considered in model formulation.

Components of the model should include hydrology, water erosion-sedimentatior wind erosion, nutrient cycling, crop growth, tillage, and animal uptake for range and pasture.

When validated, the model should be useful in determining the soil loss-productivity relationship. Simulations will be necessary for many locations in the U.S., to adequately represent varying climatic conditions and soil characteristics. Also, simulations will have to be repeated for various management strategies at each location. These simulations must be long-term (100-500+ years) to show the effect of poor management decisions on productivity.

Model output will include accumulated erosion, annual crop yields, nutrient losses, annual fertilizer application rates, off-site sediment deposition, downstream nutrient yields to streams and reservoirs, and energy requirements for tillage and maintenance. From this output, accumulated erosion can be related to crop yield mathematically. Beside providing vitally needed information for national policy planning (1985 RCA Report), the erosion-productivity relationship will enable soil loss tolerance limits to be set in an objective manner. Also, the monetary value of soil loss can be determined through reduced yields, increased fertilizer and energy requirements, and downstream damages.

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Fig. 1. Severely eroded rangelands such as is shown for this site in the Santa Rita Experimental Range near Tucson, AZ are difficult to restore economically.

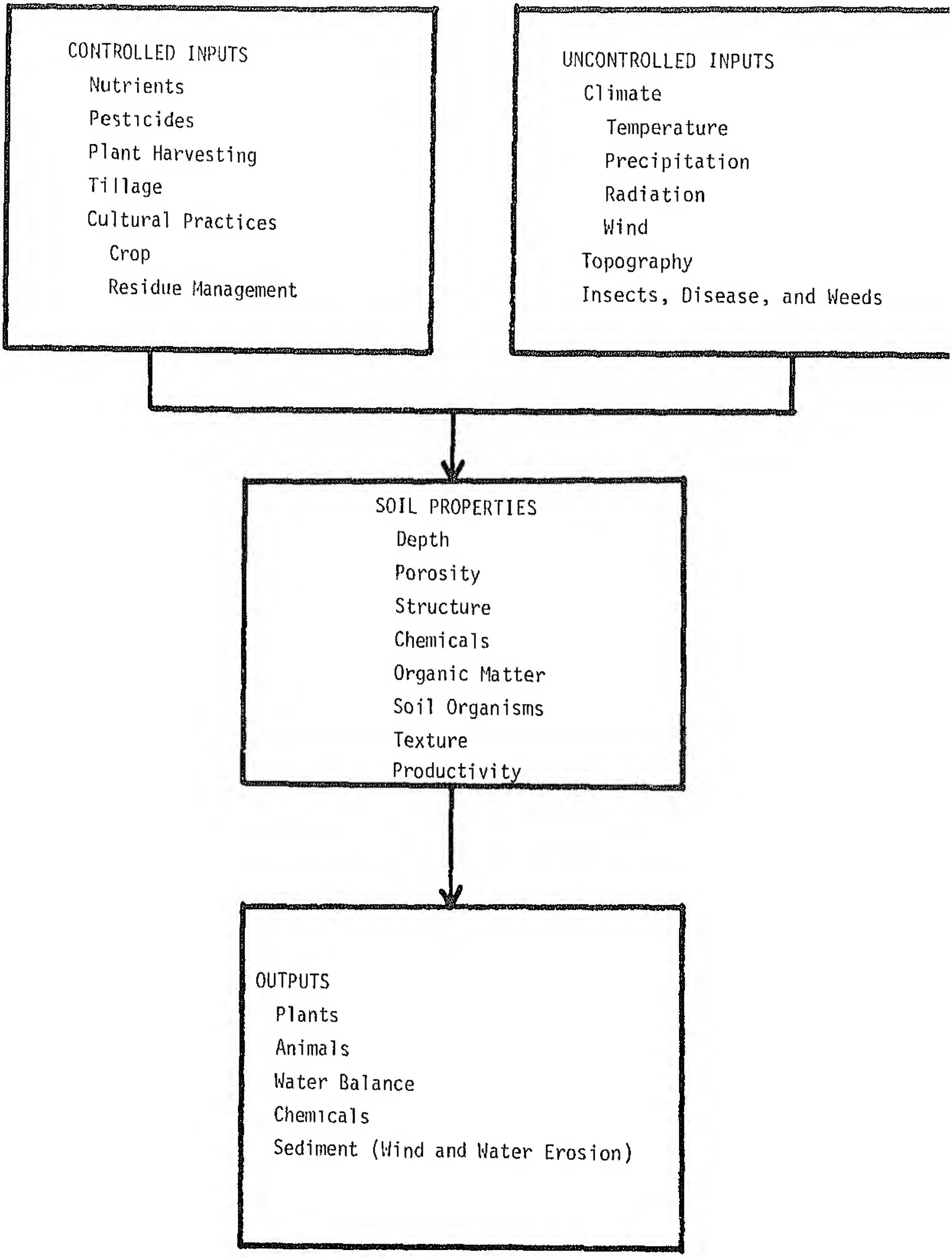

Fig. 2. Items to be considered in model formulation for quantifying the role of soil erosion and soil productivity.

RESOLUTIONS AND RECOMMENDATIONS

D. A. Farrell and E. L. Neff[1/]

The following resolutions and recommendations were developed from the responses received from the Workshop participants. Emphasis has been given to those issues which appeared to be of broad interest or concern.

1. The Workshop participants formally recommend the establishment of an interagency work group to adapt the Universal Soil Loss Equation (USLE) for use on rangelands. Action agency representatives at the workshop consider this developmental project their highest priority need, one that should be implemented as soon as practicable. They stressed their concerns that far reaching land management decisions are being made now and that action agencies cannot wait until all the research data needed for general validation of rangeland erosion prediction procedures has been acquired.

2. The participants recommend that research to adapt the CREAMS model for use on rangelands be accelerated. The capacity of the CREAMS model to predict soil erosion and soil deposition on landscapes with complex slopes and to compute soil loss on a storm event basis was viewed by scientists as a major advantage. Bureau of Land Management (BLM) and Soil Conservation Service (SCS) representatives stressed the importance of sediment yield prediction in their Agency's watershed development and management programs. Because the CREAMS model is better suited to sediment yield prediction than prediction procedures based on adjusting USLE erosion estimates with experimentally determined sediment delivery ratios, this critical BLM and SCS need can be most effectively met through adaptation of the CREAMS model to rangeland watersheds.

3. There was general agreement that improved estimates of soil erosion from rangelands would require a major research effort directed toward determining realistic values of soil erodibility. There was considerable uncertainty about the reliability of procedures now in use and much discussion and speculation on the appropriate experimental procedures to be used for determining erodibility. There was broad concensus that the following issues must be considered:

a. For simulated rainfall plot studies, a standard series of storms should be developed for estimating erodibility. The procedures used by Wischmeier and Mannering in developing

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1/ National Research Program Leader, NPS-SWAS, SEA-AR, USDA, Beltsville, Maryland, and Hydraulic Engineer, Northern Plains Soil and Water Research Center, SEA-AR, USDA, Sidney, Montana, respectively.

the erodibility nomograph widely used to estimate K for cropped soils may not be appropriate for arid and semi-arid rangelands.

b. The standard fallow plot used for cropland soils is inappropriate for rangelands. A bare plot developed and maintained through chemical control of rangeland vegetation should be used as the standard for rangeland erosion.

c. The minimum length of experimental plots should be 20 feet. Plot width and length should be selected to ensure that the overland flow patterns are not severely distorted or constrained by the plot dimensions.

d. Where substantial disturbance to the soil surface results from vegetation removal, a restoration period of from one to 2 years, depending on climate, may be needed to stabilize plot response. Experimental studies are needed to determine the effects of degree of disturbance and time since disturbance on soil erodibility.

e. Limited experimental studies have shown that soil loss may be substantially reduced by the erosion pavement (stone cover) found in many rangeland areas. Currently, the erosion pavement is treated as a factor modifying soil erodibility. Whether the erosion pavement is ultimately considered a modifying erodibility or cover factor its effect on soil loss is substantial and must be evaluated.

4. The experimental data used in the development of the Universal Soil Loss Equation (USLE) was obtained for landscapes characteristic of croplands. Slopes of 30 percent and above are common in a rangeland environment as are slope lengths of 500 feet and longer. Guidelines currently in use by some agencies arbitrarily limit slope length to a maximum of 500 feet. Research is needed to validate the length-slope factor of the USLE for the steep terrain and long slopes commonly found on rangelands and to provide scientific guidelines for determining effective slope length.

5. Few participants expressed major concern or interest in further studies of the rainfall factor. The primary research issue appears to be related to soil loss from rangelands accompanying snowmelt or rainfall when the surface soil is frozen. Under these conditions there is some evidence, albeit inconsistent, that rainfalls of low to moderate intensity can produce substantial erosion. Observed inconsistencies in rangeland responses appear to be related to the hardness of the "frozen condition." Additional research is needed to improve our understanding of the freeze and snowmelt processes

and to delineate the physiographic areas where snowmelt and rainfall on frozen ground can produce substantial erosion.

6. There was much skepticism about the validity of the procedures currently used to compute the cover and management factor for rangelands. The lack of an adequate data base is acknowledged by research scientists and technical specialists in the action agencies. There is virtually no field data for determining the effects of management practices such as seeding and grazing, pitting, contour furrowing, brush control, and controlled burning. Information is urgently needed on how to measure and specify vegetation characteristics. The effects of litter, rock-vegetation mixtures, and erosion pavements need to be determined for a wide range of conditions. Questions that need answers include: What are the effects of seasonal changes in vegetative cover on the C-factor? What is the magnitude of the change in the C-factor? Can we devise a standard procedure for obtaining the field data needed to determine the C-factor? Success of the planned rangeland research aimed at developing comprehensive rangeland management systems may well hinge on objective answers to these and related questions.

7. As with most of the factors in the Universal Soil Loss Equation, there is little field data to establish quantitatively the influence of conservation practices on erosion, thereby providing a basis for estimating associated P-factors. Limited experimentation has indicated that the effectiveness of many conservation practices decreases with time. Substantially more research at plot and watershed scales is needed to quantify the transient nature of the P-factor and relate the effectiveness of conservation practices to climatic, grazing intensity, topographic and soil descriptors. A difficulty, unique to the application of the USLE to rangelands, is the uncertainty regarding the appropriate value of the P-factor for the "natural landscape." Several of the workshop participants questioned the validity of assigning a value of unity to the P-factor for these "undisturbed" areas. Of concern was the effect of microtopography, brush, debris, tracks, and other irregularities on the deposition of sediment and on landscape modification at the microscale level.

8. There was general agreement that more attention must be given to establishing soil loss tolerances for rangelands. Several erosion specialists questioned whether soil loss can be viewed in a meaningful way unless related to site specific tolerances. In essence, they would like to express erosion rates in terms of changes in potential productivity and long-term site stability. Action agency representatives seemed convinced that soil loss tolerances for rangelands

cannot be established using criteria appropriate to croplands. Faced with making major land management decisions with no well-defined guidelines, they would prefer to set soil loss tolerances at levels close to the natural erosion rates. Without definitive field studies to establish the relationship between cumulative erosion and rangeland productivity it will be difficult, and possibly unwise, to moderate the present conservative philosophy on rangeland erosion.

9. Experience with "natural" erosion plots has shown that acceptable estimates of average annual soil loss cannot be obtained with less than 15 or more years of data. For the large temporal and spatial variabilities associated with rainfalls in arid and semi-arid environments the long monitoring period that is needed and the large associated experimental costs make the approach unattractive and possibly impractical for many scientists. Soil loss data obtained from plots subjected to simulated rainfalls of varying intensity and duration have been widely accepted as a viable alternative source of information. While the optimum and desirable characteristics of simulated rainfalls have been debated for some time, research is needed to establish the errors associated with differences between the characteristics of naturally occurring and simulated rainfalls. Key characteristics requiring urgent research attention are kinetic energy and drop size distribution.

10. Notwithstanding the considerable literature that exists and the many workshops that have been held on rainfall simulators and small plot studies, the controversy that has surrounded these issues for several decades remains. Questions which surfaced at this workshop and which need to be urgently resolved include: Do small plot simulators have a role in erosion research on rangelands? Can this role be defined? Will small plot studies provide meaningful estimates of sheet erosion rates? Would small and large plot studies provide the same ranking of range sites in a regional or national survey of rangeland erosion? Are comparisons of sheet erosion losses for different soils and vegetative covers of value in management decisions? While most of the workshop participants conceded that erosion studies at both plot and watershed scales contribute to the body of scientific knowledge on erosion and that they can assist in the development of prediction procedures, the roles of the various approaches remain uncertain and poorly defined. Consequently, unless a substantially greater effort is made to establish firm guidelines for future experimental studies, there is an unacceptably high probability that a considerable time and effort will be expended on research of marginal value.

The issues and recommendations discussed above were surfaced by the workshop participants during the workshop and provided to us in the form of written statements. Every effort has been made to address the major issues and consolidate those recommendations that were submitted by two or more participants. We trust that there are no serious omissions and ask all research scientists and technical specialists concerned with soil erosion from rangelands to provide strong support for these resolutions and recommendations through their personal efforts to draw the attention of State and Federal organizations, agencies, and institutions to the need for increased financial support and higher regional and national priorities.

APPENDIX A

The following material was developed by George E. Dissmeyer following the March, 1981 Erosion Workshop. The material represents an example of an approach for estimating USLE parameter values for desert brush and grassland conditions such as those frequently encountered in the Southwest.

REPORT ON APPLICATION OF THE USLE TO DESERT BRUSH AND RANGELAND CONDITIONS

George E. Dissmeyer[1]

On May 11, 1981 I went to Albuquerque, New Mexico to assist the U.S. Forest Service, Southwestern Regional Office, in applying the Universal Soil Loss Equation (USLE) to desert brush, pinyon-juniper, and grass rangeland. This report summarizes the observations made, recommended modifications in the component subfactor approach for those conditions, and other recommendations.

The Southwestern Region had been using Table 10 in Agricultural Handbook 537 (4) and asked for assistance in building steps, contour tillage, and depression storage (1,2) into their procedures. Table 10 includes the effects of ground cover (conversely, of bare soil), canopy, fine roots, and soil reconsolidation (held constant at 0.45). The table assumes, although not stated in Agricultural Handbook 537, that the area under the plant canopy would have fine roots in the surface inch of topsoil. However, several desert brush and rangeland conditions were found that do not fit the conditions assumed in constructing Table 10. Deviations from Table 10 assumptions are discussed in appropriate sections of this appendix.

Observers in the Southwestern Region included surface rock fragments measuring 3/4 inch and larger in ground cover. Smaller stones and fragments were omitted. This criteria is an outgrowth of range survey techniques. However, for the USLE, a rigid size standard cannot be applied. For more reliable results, inspect the surface rock and judge which stones and pebbles will remain in place under a heavy rain. (Figure 1.) All stones and rock fragments

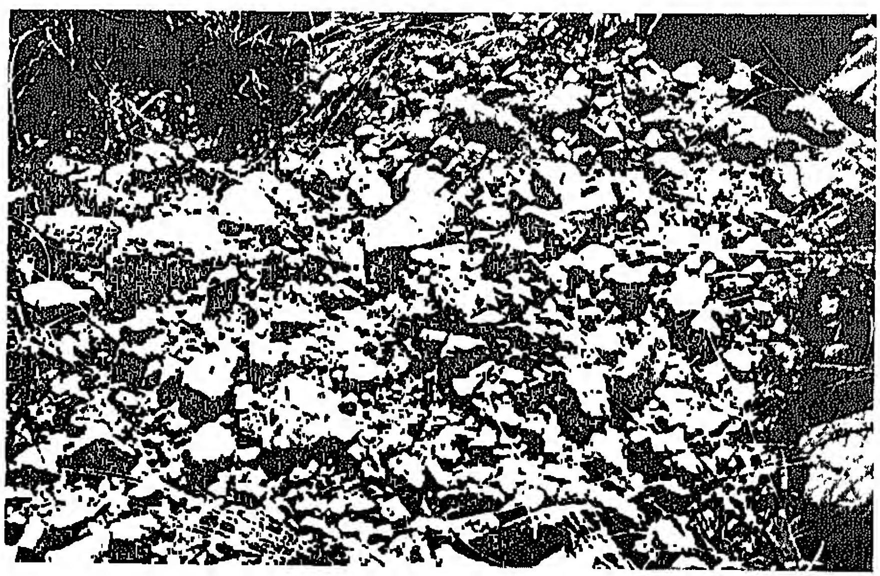

Figure 1. Effective rock ground cover

[1]Staff Hydrologist, USDA Forest Service, Southeastern Area, Atlanta, Georgia.

in Figure 1 are judged to offer effective protection of the soil surface. Small pebbles in this picture will remain in place because they are lodged against each other, larger stones, and clumps of grass. However, if small pebbles were widely-spaced on a soil surface, they would be free to be moved by surface runoff and should not be counted as ground cover.

Rocks are part of the ground cover in many desert rangeland conditions. Grass and other herbaceous vegetation less than 6 inches tall are considered as part of the ground cover in Table 10. Table 10 was prepared with the assumption that fine roots occur under the vegetation's canopy (4). By including stones or rock fragments as ground cover, users of Table 10 would be forced to assume that there are fine roots under the rocks. However, fine roots are frequently absent in the top inch of soil under and between rock fragments - a condition which can cause significant errors in predicted erosion.

Steps (1, 2) were found in several situations (Figure 2). In one situation, the step was completely covered by stones and rock fragments and formed behind a clump of grass. It appears that the rock creeps downhill by gravitation and accumulates behind clumps of grass and other obstacles. The surface of the rock forming on steps has a grade of 7 to 10 percent, depending upon the size of the rock (Figure 3). Rock cover was removed on a couple of steps to see if soil had formed a step below. It had, and its grade was approximately 3 percent, as found in the East (Figure 3).

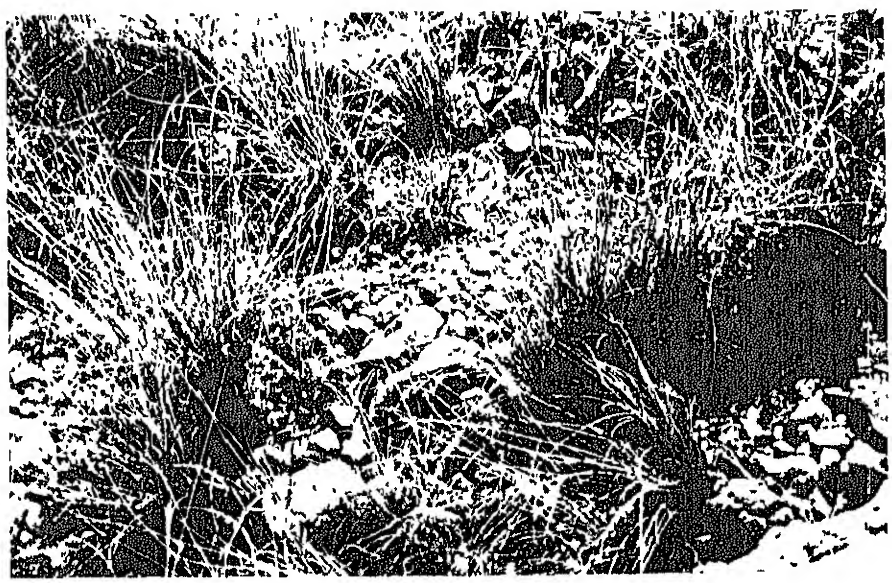

Figure 2. Typical step found in desert grassland

The observer cannot judge the rooting characteristics of plants by broad vegetation types - grass vs. weeds in Table 10. In a desert grassland, I inspected the rooting characteristics of several plants. Generally, a few coarse roots extended straight down into the soil with no surface lateral roots (Figure 4). Table 10 was prepared on the assumption that the area of fine lateral roots corresponds to the area of canopy. In this situation, no fine

roots were found in the top soil under the canopy except for the area of the root collar. The application of Table 10 to this situation will cause errors in predicted erosion rates.

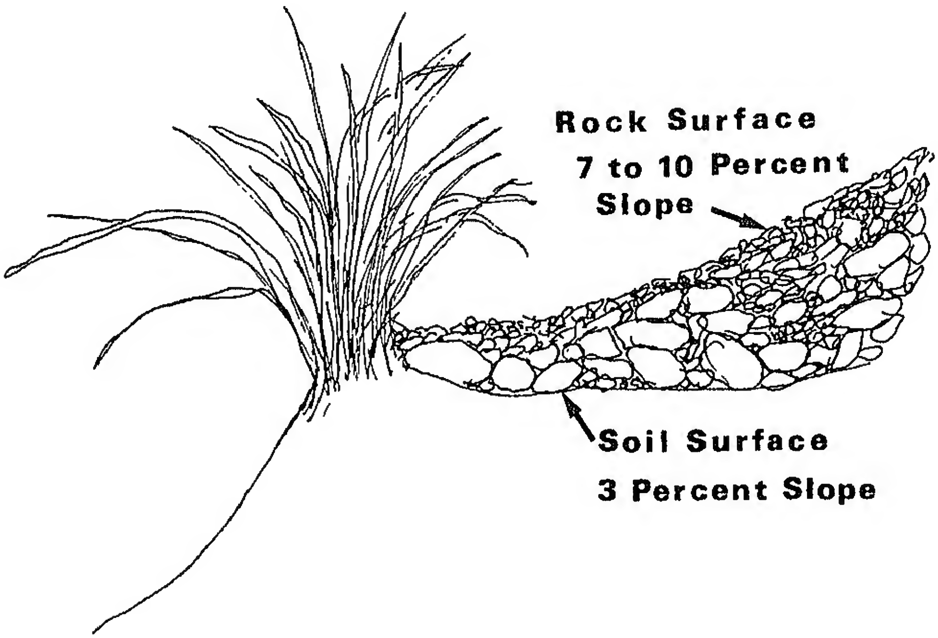

Figure 3. Typical cross-section of step found in desert

In another grassland area, the plants had extremely fine lateral roots in the top inch of soil. The roots resembled a very fine spider web and were very hard to see. They had very little tensile strength and offered no deductible resistance when I broke the soil aggregates apart. Thus, these roots cannot be considered as an effective fine root mat. These extremely fine roots are probably killed and oxidized when the soil becomes extremely hot during the summer.

Thus, it became apparent that the fine lateral-rooting characteristic of plant species is highly variable and <u>cannot</u> be judged by broad groupings of plants (weeds vs. grass, as in the East) (1, 2, 3). The observer must inspect the topsoil for the presence of fine roots under canopies and between canopies. This advice, and the findings mentioned earlier, were reconfirmed in all subsequent stops, which included the careful examination of rooting characteristics of plants.

The next stop was at a dense pinyon-juniper stand. Litter was found under the tree canopy near the stem. An inspection of exposed topsoil for fine roots revealed another type of rooting pattern (Figure 5). A dense, fine root mat was found at each point inspected, <u>but</u> at a depth of 1 to 1.5 inches. About 1 to 1.5 inches of loose topsoil covered the mat. This kind of root mat offers

no appreciable benefit in reducing sheet and rill erosion. Thus, no should be given to fine roots here.

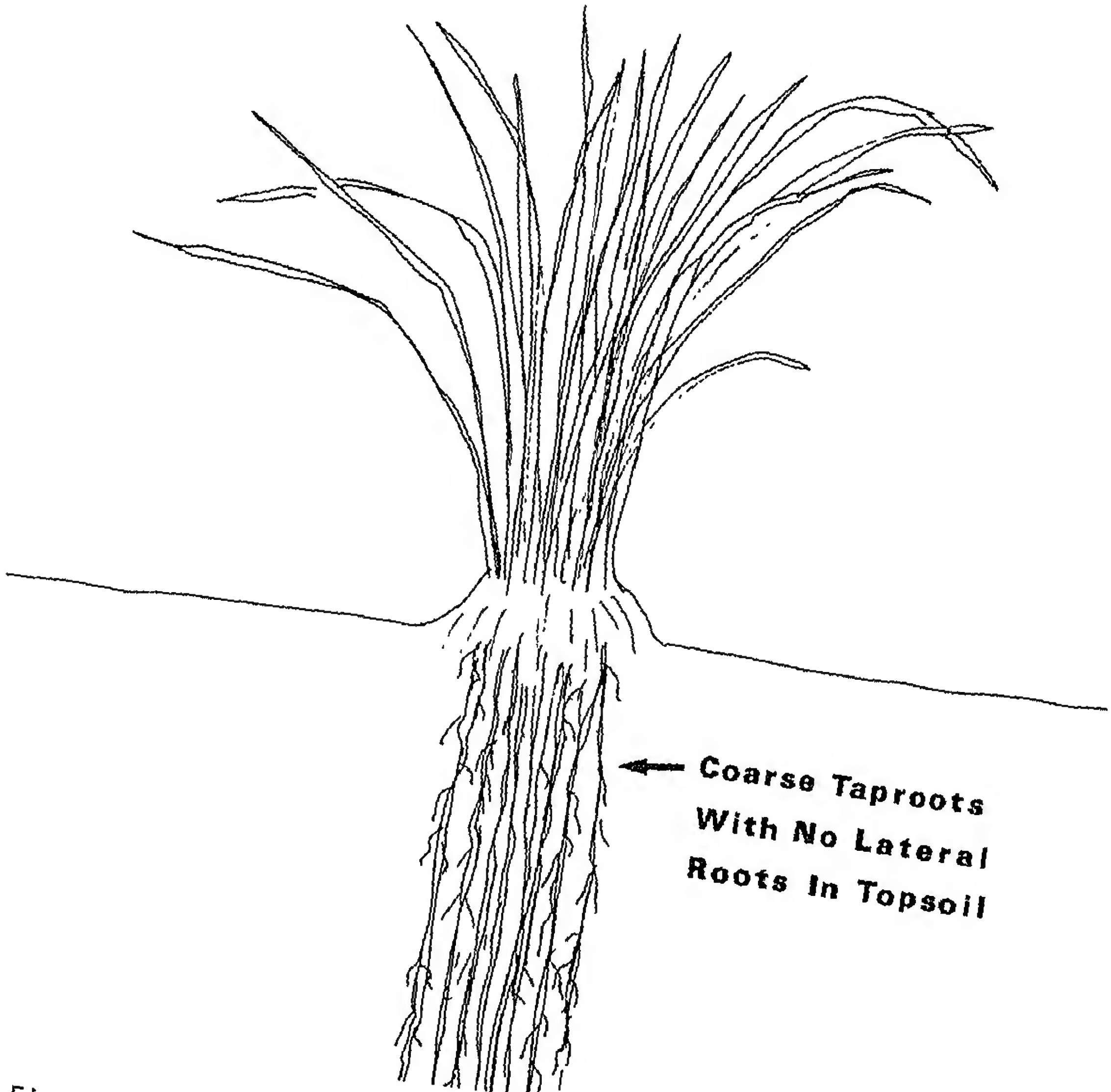

Figure 4. Rooting characteristics of some observed grasses

Several things were observed at a higher elevation grassland (blue grama). Blue grama has a good fine lateral root mat in the topsoil occupying the total area (Figure 6). Also, blue grama grows on soil pedestals up to 1 inch in height. Observers may misjudge these pedestals as an indication of serious rangeland erosion. Grass and other vegetation types are accumulators of splash

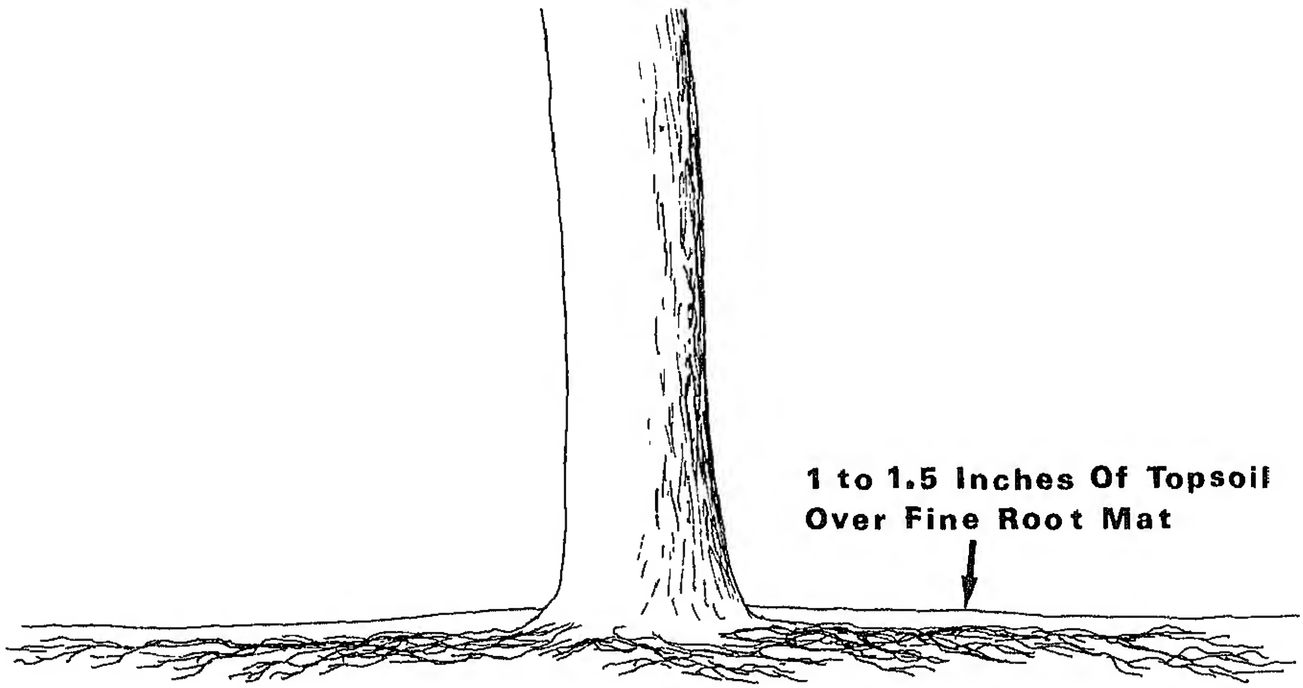

Figure 5. Rooting characteristics of pinyon-juniper

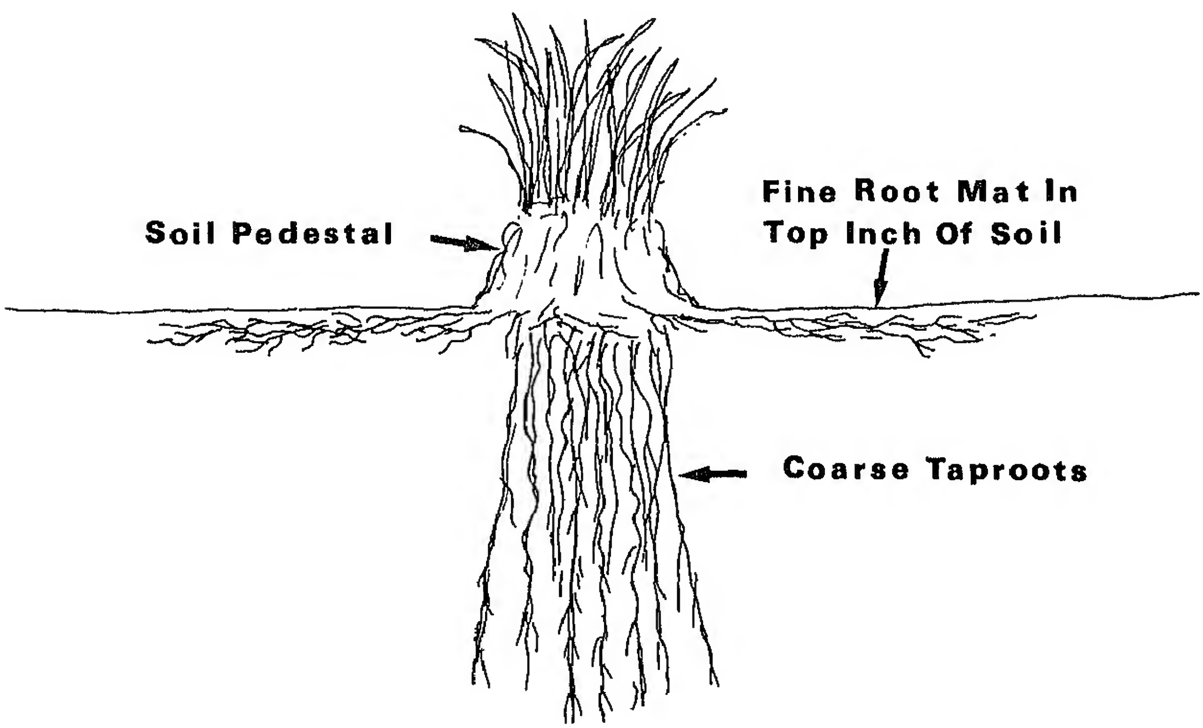

Figure 6. Blue grama on soil pedestals

and wind erosion. Over time, a pedestal forms with grass growing on top. Blue grama lives for 7 to 10 years and succeeds itself on the pedestal. Therefore, these pedestals may represent several decades of accumulation.

Two additional observations support this assertion. Figure 7 displays blue grama growing on pedestals; two pine cones lie nearby on bare soil. The pine cones were well-weathered and, because wood takes decades to decompose, they probably have been in place for 10 or more years. No pedestals occurred under the cones.

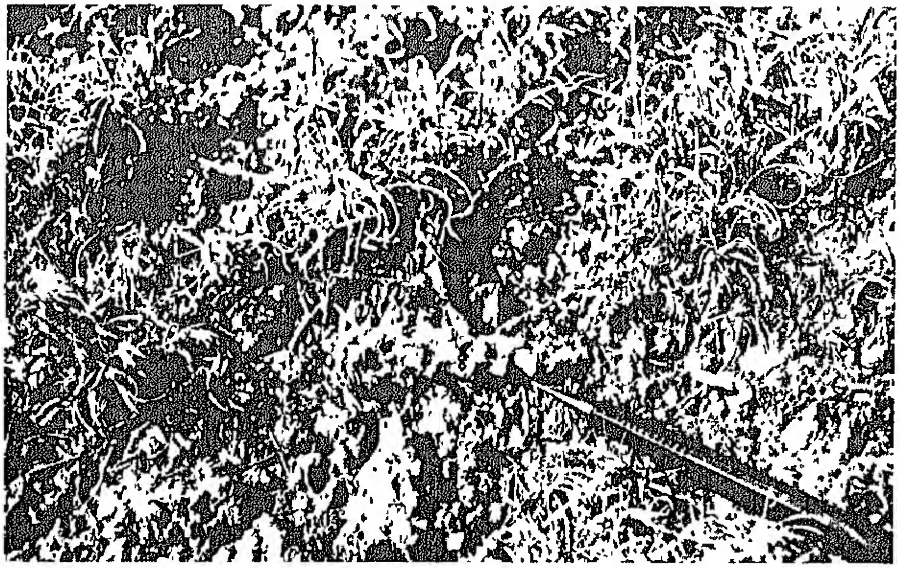

Figure 7. Pine cones without pedestals under them

The predicted erosion rate for this area, using the USLE, was 0.03 tons per acre per year. Is this a reasonable rate? Evidence suggests this area incurs little erosion. The area had been "pitted" to stimulate blue grama growth 9 years ago (Figure 8). Shallow pits are created 1.5 to 2.0 inches deep. After 9 years, no significant sediment had accumulated in these pits.

On-site depression storage was significant, including the pits. Also, micro-ridges were formed by pedestaled blue grama which created "walled" catchments for sediment (Figure 8). On-site depression storage was estimated at 0.3 for this site.

The final observation made at the blue grama site was the apparent slow decomposition rate of fine roots (Figure 9). An inspection of the small piles of soil, thrown up by the pitting operation, revealed fine roots still intact and protruding out of the soil 0.25 to 0.5 inches. These mounds were created 9 years ago, and these roots were still offerring a substantial binding effect. The resiudal binding effect curve used for forest conditions in the East assumed a 4-year decay period for this effect (Figure 10) (1). It appears that for blue grama, the residual binding effect will persist for 10 or more years. Substituting a 10-year decay period in the residual binding effect figure may be warranted (Figure 11).

Figure 8. Pitted blue grama

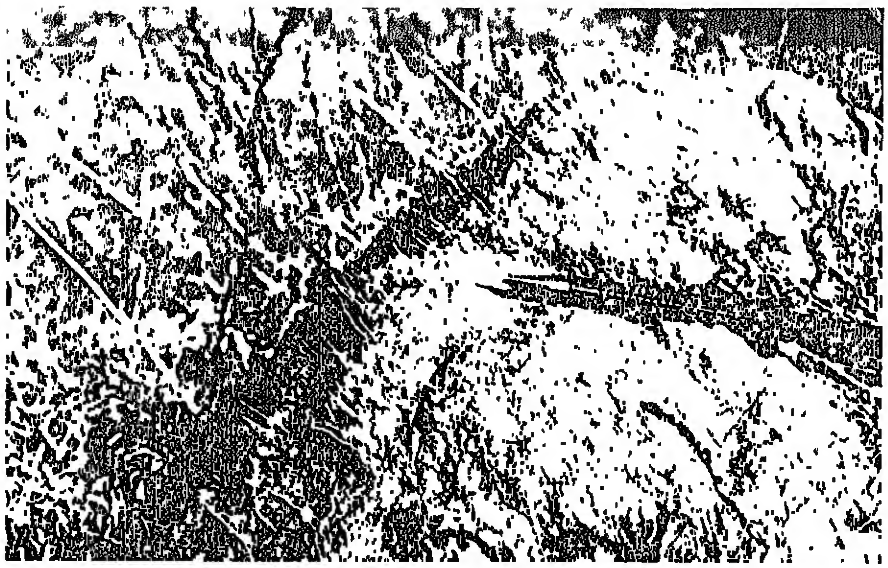

Figure 9. Nine-year-old roots of blue grama decomposed slowly

Residual binding warrants further study, and if significant differences in ratings are found, a revised Figure 10 could be constructed. Possibly, an interim figure can be constructed reflecting the findings of the study and local experience, or Figure 11 could be used as a stopgap revision until something better can be developed. Warning: Other situations may be found where fine roots decay in 2 to 4 years, or some other period of time, thus requiring more than one set of curves.

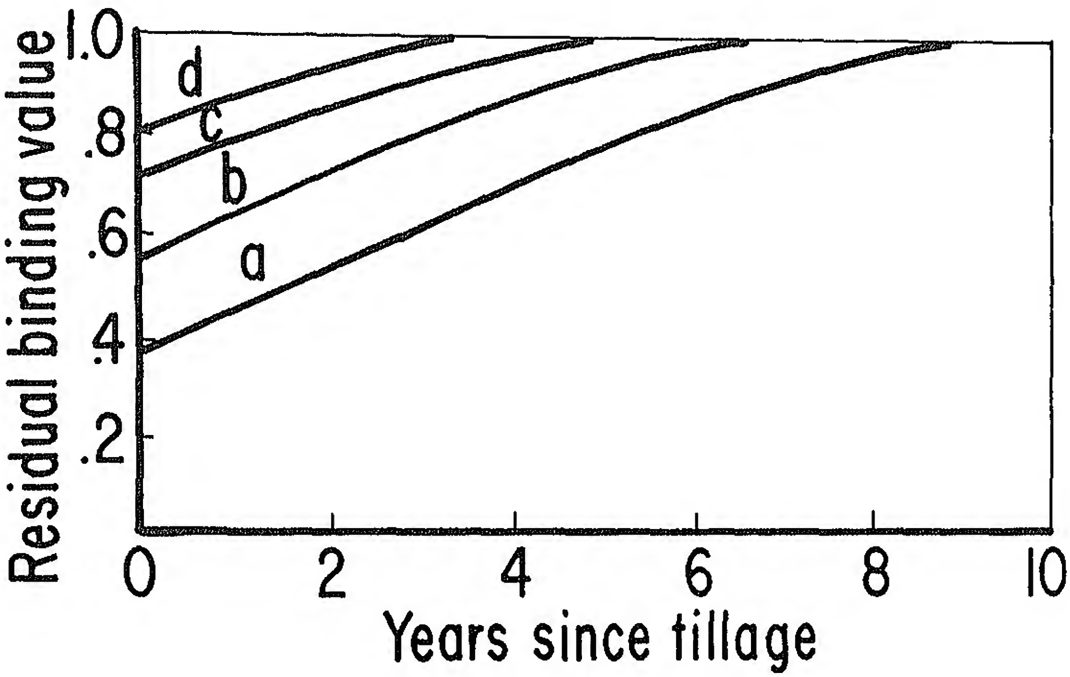

Figure 10. Residual binding subfactor (East)

Legend:
a. Topsoil has good initial fine root mat; subsoil has good structure and permeability

b. Topsoil has poor initial fine root mat; subsoil has good structure and permeability

c. Topsoil absent with poor initial fine root mat; subsoil has good structure and permeability

d. Topsoil absent with poor initial fine root mat; subsoil has poor structure and permeability

Sagebrush has a fine root mat in topsoil that extends 8 to 10 inches beyond the crown (Figure 12). The center of the space between bushes can be void of fine roots if the plants are far enough apart. Table 10, if applied to this sagebrush, would cause errors in the predicted erosion.

The soil occupying a grassland experiences substantial shrinking and swelling in response to soil moisture changes (Figure 13). These cracks offer depression storage opportunity and should be considered in erosion predictions. However, the size and distribution of these cracks vary greatly throughout the year and from storm to storm. This variability must be considered in developing long-term average erosion rates.

A logged area was visited that had the same fine rooting characteristics as eastern forests (Figure 14). Here, fine roots occupied the total area. Applying Table 10 in Handbook 537 considerably increased the predicted erosion rate. Again, Table 10 was designed on the assumption that fine roots are found only under the crown.

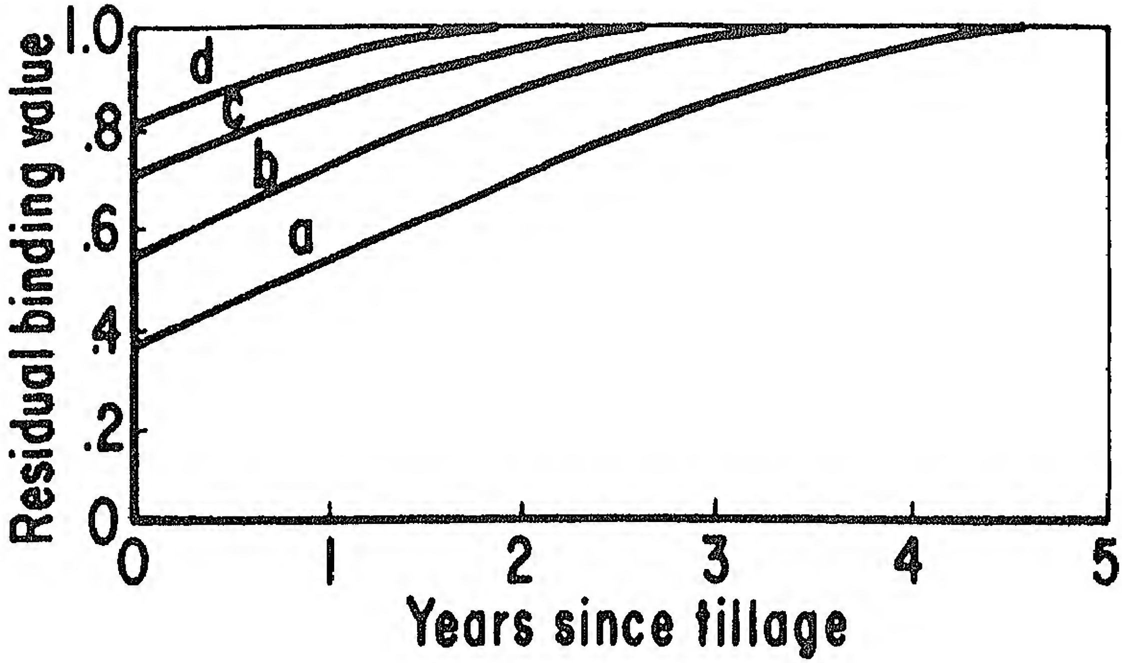

Figure 11. A possible adjustment in the residual binding subfactor for blue grama

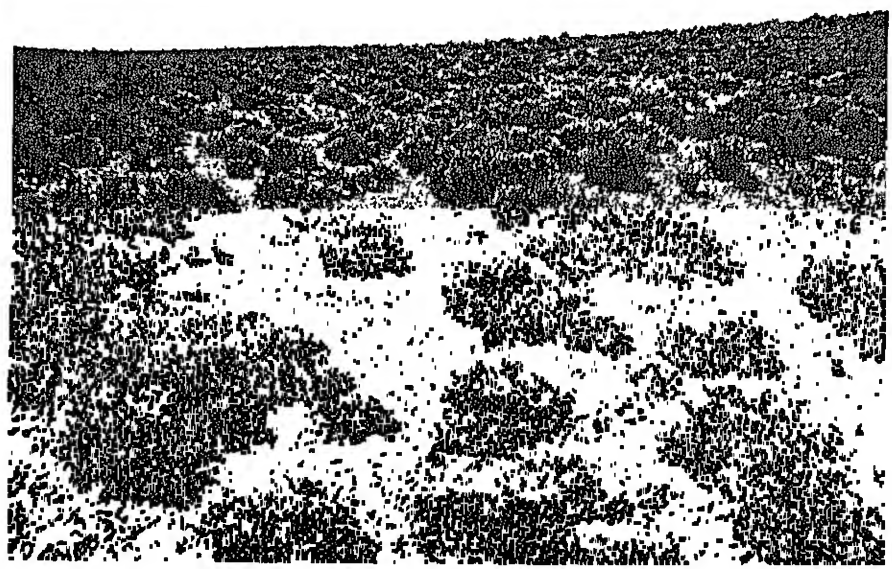

Figure 12. Sage brush

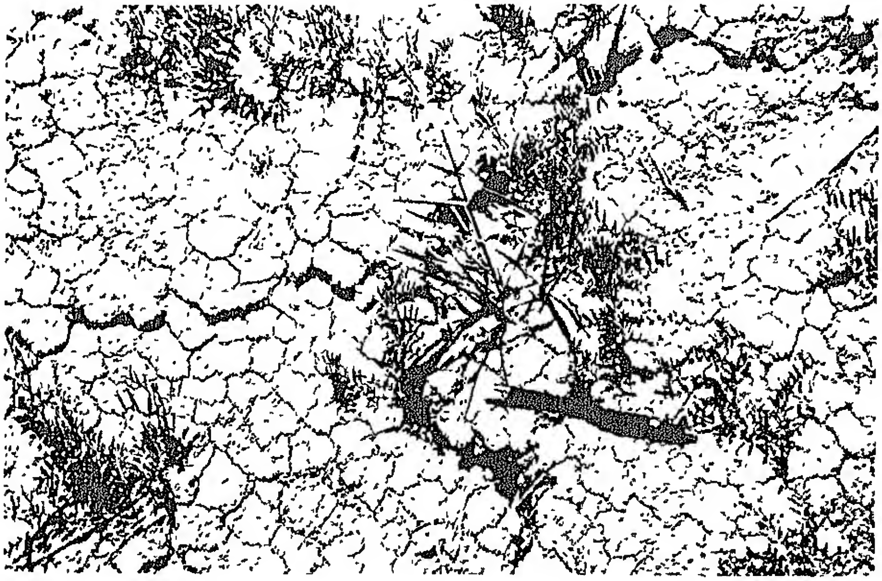

Figure 13. Soil cracks

Figure 14. Logged forest

In general, slope lengths were being properly interpreted in the field. One variation on slope length interpretation was observed (Figure 15). Bedded rock outcrops can define the top and bottom of the slope. Surface runoff will be funneled through niches in the outcrop.

Finally, the USLE is being misapplied to badlands (Figure 16). The erosion process operating here is more like gully erosion than sheet and rill erosion.

Figure 15. Slope length between rock outcrop

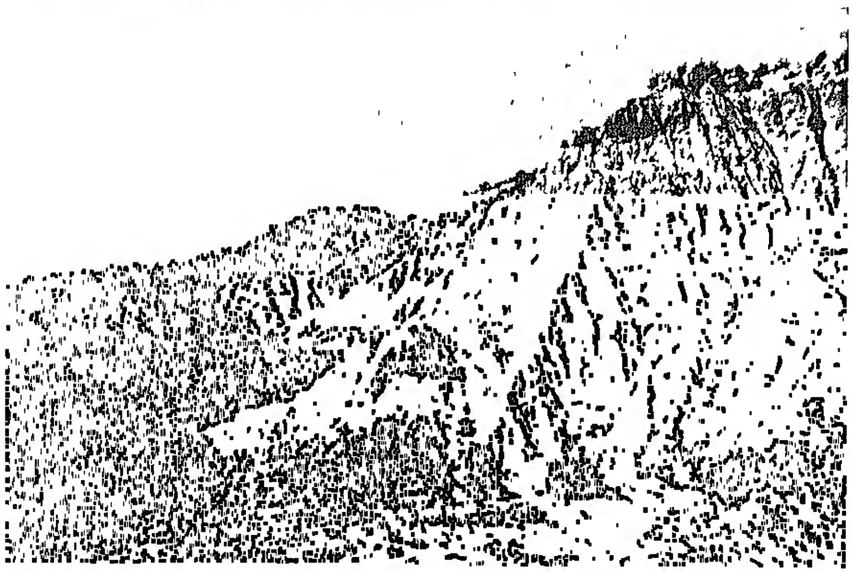

Figure 16. Badlands where USLE is being misapplied

In general, the component-subfactor approach for developing the cover-management factor (C) can be adapted, with some modification and validation, to northern New Mexico conditions. The participants in this project felt comfortable with the procedure.

There are obvious problems in applying Table 10 to this area, as described earlier. The Southwestern Region should move away from Table 10 as soon as possible (realizing it takes time to change procedures and train people). The decay rate of tilled fine roots needs additional study and, probably, a revised residual binding relationship should be developed.

Predicted erosion rates of less than 0.5 tons per acre per year probably ave more validity in New Mexico than in the East (1, 2). The reason for low

rates is low R values, not bare soil, as in the East. Substantial bare soil exists and is interconnected in the desert. Thus, when surface runoff occurs, paths are available to transmit runoff and soil to the toe of the slope.

Probably, the biggest source of variation is in "R". The limited number of storms, widely scattered in space and time, makes "R" highly variable from year to year and, perhaps between decades. Thus, very long-term precipitation records may be needed to develop a meaningful average annual "R". A 22-year record, as used in the East, probably will not contain enough data.

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APPENDIX B

WORKSHOP PARTICIPANTS

Suraj Ahuja
USDA-FS
Prescott National Forest
P.O. Box 2549
Prescott, AZ 86301

H. P. Binger
USDA-ARS
1333 Broadway, Suite 400
Oakland, CA 94612

Jack Bohning
USDA-FS
Prescott National Forest
P.O. Box 2549
Prescott, AZ 86301

N. J. Chatterton
USDA-ARS
Utah State University
UMC 48
Logan, UT 84322

A. G. Darrack
USDA-FS
P.O. Box 3623
Portland, OR 97208

G. E. Dissmeyer
USDA-FS
1720 Peachtree Rd., N.W.
Atlanta, GA 30309

Jay W. Eby
USDA-FS
Prescott National Forest
P.O. Box 2549
Prescott, AZ 86301

W. E. Emmerich
USDA-ARS
442 E. 7th St.
Tucson, AZ 85705

D. A. Farrell
USDA-ARS
Rm. 234, Bldg. 005
BARC-West
Beltsville, MD 20705

G. R. Foster
USDA-ARS
Purdue University
Agric. Engr. Department
Lafayette, IN 47907

Don Fulton
USDA-SCS
West Technical Service Center
511 NW Broadway
Portland, OR 97209

Karl Gebhardt
USDI-BLM
550 W. Fort St.
Boise, ID 85724

Jerry Harman
USDI-BLM
P.O. Box 12000
Reno, NV 89520

G. E. Hart
Utah State University
Dept. of Forest & Outdoor Recreation
College of Natural Resources
Utah State University
Logan, UT 84322

WORKSHOP PARTICIPANTS

D. M. Hartley
USDA-ARS
P.O. Box E
Ft. Collins, CO 80522

J. Holeman
USDA-SCS
P.O. Box 2890
Washington, DC 20013

C. W. Johnson
USDA-ARS
Patti Plaza, Suite 116
1175 S. Orchard
Boise, ID 83701

Marc G. Keplan
USDA-FS
301 W. Congress
Tucson, AZ 85701

J. M. Laflen
USDA-ARS
Iowa State University
Davidson Hall
Ames, IA 50011

Leonard J. Lane
USDA-ARS
442 E. 7th Street
Tucson, AZ 85705

Steven Loomis
USDI-BLM
Bldg. 50, Denver Fed. Center
Denver, CO 80225

Collis Lovely
USDI-BLM
18th and C Streets NW, Rm. 2528
Washington, DC 20240

L. D. Meyer
USDA-ARS
USDA-Sedimentation Laboratory
P.O. Box 1157
Oxford, MS 38655

D. K. McCool
USDA-ARS
Washington State University
Smith Agric. Engr. Bldg.
Pullman, WA 99164

E. L. Neff
USDA-ARS
P.O. Box 1109
Sidney, MT 59270

H. B. Osborn
USDA-ARS
442 E. 7th St.
Tucson, AZ 85705

Waite Osterkamp
USDI-USGS
431 National Center
Reston, VA 22091

Carl E. Pachek
USDA-SCS
Federal Building
230 N. 1st Avenue
Phoenix, AZ 85025

Dick Page
USDI-BLM
University Club Bldg.
136 E. South Temple
Salt Lake City, UT 84111

Dennis Phillippi
USDA-SCS
P.O. Box 970
Bozeman, MT 59715

Donald Post
Soils, Water & Engr. Dept.
Rm. 406, Ag. Sci. Bldg.
University of Arizona
Tucson, AZ 85721

K. G. Renard
USDA-ARS
442 E. 7th Street
Tucson, AZ 85705

Dave Richmond
USDA-SCS
Rm. 3008, Fed. Bldg.
230 N. First
Phoeniz, AZ 85025

Mike Rollins
USDI-BLM
P.O. Box 30157
Billings, MT 59107

Aubrey C. Sanders, Jr.
USDA-SCS
Rm. 3008, Fed. Bldg.
230 N. First
Phoenix, AZ 85025

J. Roger Simanton
USDA-ARS
442 E. 7th Street
Tucson, AZ 85705

Dwiatmo Siswomartono
Soils, Water & Engr. Dept.
Rm. 406, Ag. Sci. Bldg.
University of Arizona
Tucson, AZ 85721

Jim Stone
USDI-BLM
D460, Denver Federal Center
Bldg. 50
Denver, CO 80225

Eric Sundberg
USDA-FS
Forestry Science Lab.
1221 South Main Street
Moscow, ID 83843

Jerry Walker
USFS Regional Office
515 Gold, SW
Albuquerque, NM 87102

J. R. Williams
USDA-ARS
P.O. Box 748
Temple, TX 76501

J. R. Wight
USDA-ARS
Patti Plaza, Suite 16
1175 South Orchard
Boise, ID 83701

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